



**U.S. DEPARTMENT OF THE INTERIOR  
BUREAU OF LAND MANAGEMENT**

**SITE EVALUATION SERVICES CONTRACT  
CONTRACT NO. 1422-N651-C4-3049**

**JANUARY 19, 1998**

**SITE EVALUATION  
WORK PLAN**

**WARD VALLEY  
SAN DIEGO COUNTY, CALIFORNIA**

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**Tetra Tech NUS, Inc.**

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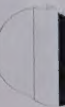
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II	HEALTH AND SAFETY PLAN
III	CONTRACTOR MANAGEMENT PLAN
IV	BRE STANDARD OPERATING PROCEDURES
V	SELECTED ASTM METHODS
VI	ANALYTICAL METHODS (TO BE DETERMINED)





## 1.0 INTRODUCTION

### 1.1 PURPOSE AND SCOPE

The purpose of the Ward Valley Site Evaluation Project is to collect representative samples of environmental media to further define the nature of water movement in the unsaturated (vadose) zone beneath the proposed Ward Valley low-level radioactive waste disposal site (Figure 1-1). The National Academy of Sciences Report (NRC, 1995) recommended further studies be conducted of the nature of water and radioisotope migration through the vadose zone.

The scope of work includes collection and analysis of soil gas, soil gas condensate, sediment core, groundwater, shallow soil, rainwater, and well development water. Activities to be conducted include drilling and coring vadose zone sediment, trenching across an interfluvial and ephemeral wash, installing soil gas sampling ports at depths from ground surface to the water table, drilling and installing monitoring wells, and sampling ground water at new and existing wells.

Additional work to be conducted in support of sample collection includes establishment of site security, providing site office and sample handling facilities, shipping samples to the laboratories, performing data validation and compiling analytical results. All work conducted during this field effort will be in accordance with the Sampling Protocols provided by Bureau of Land Management (BLM), the ASTM procedures referenced, and/or Tetra Tech NUS (formerly Brown & Root Environmental) Standard Operating Procedures (SOPs).

### 1.2 PROJECT ORGANIZATION

#### 1.2.1 Organization Chart

The field logistics and sampling portion of the project will be conducted by Tetra Tech NUS (TtNUS) under the direction of BLM National Applied Resource Center (NARSC). The project organization is shown in Figure 1-2, which includes the subcontractors selected to perform drilling, surveying, laboratory analysis, and security support. The primary laboratory, Lawrence Livermore National Laboratory (LLNL), will receive samples from TtNUS under chain of custody, however the lab will be contracted by the BLM.

# Introduction

## 1.1 Background

The purpose of this study is to investigate the effects of various factors on the performance of a system. The study is divided into two main parts: a theoretical analysis and an experimental investigation. The theoretical analysis will focus on the development of a model that can predict the system's behavior under different conditions. The experimental investigation will involve the design and implementation of a series of tests to validate the model and to determine the range of conditions over which it is applicable.

The first part of the study will involve a detailed examination of the system's components and their interactions. This will include a review of the relevant literature and a comparison of the system's performance with that of other similar systems. The second part of the study will involve the design and implementation of a series of tests to validate the model and to determine the range of conditions over which it is applicable.

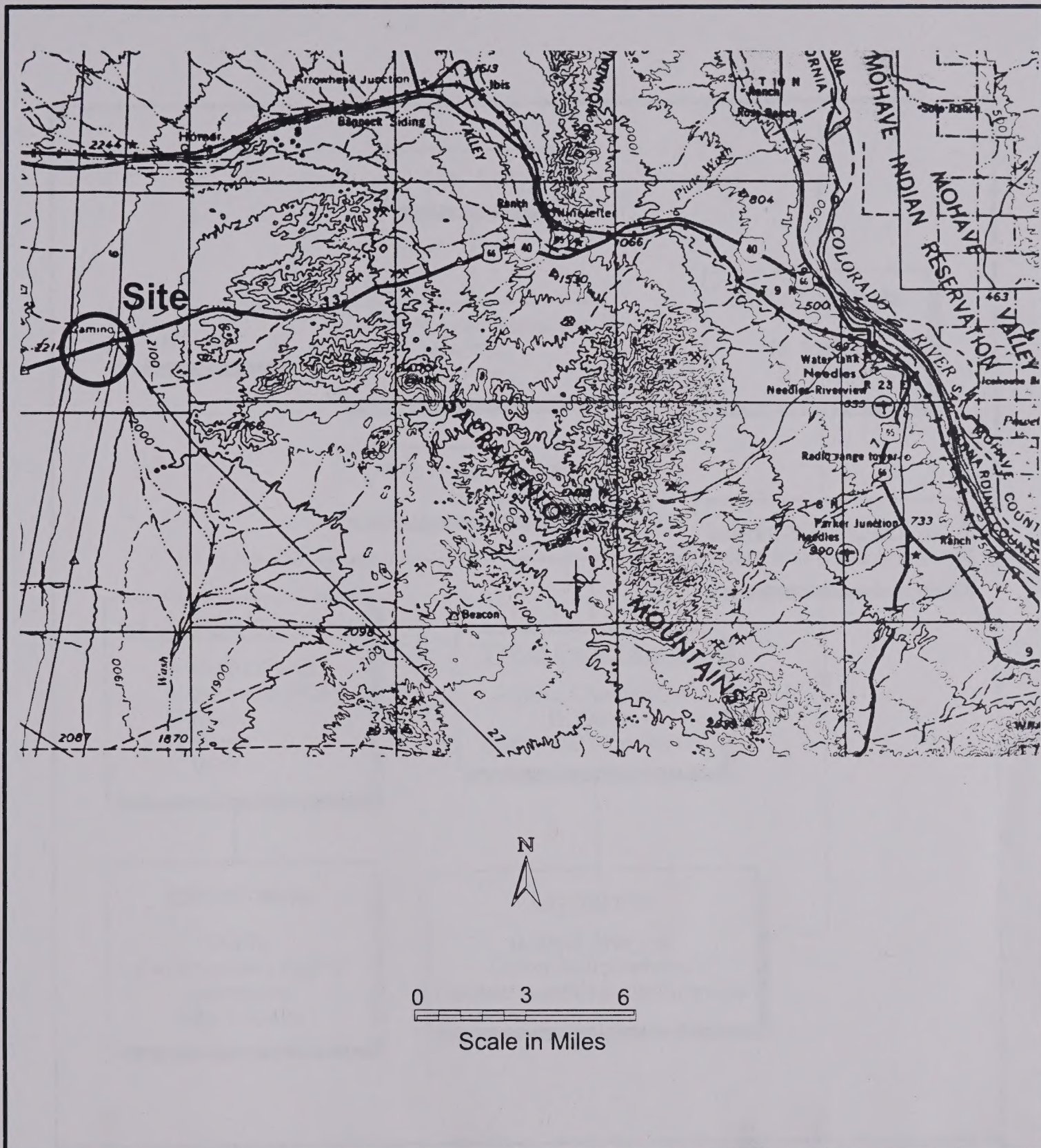
The results of the study will be presented in a series of tables and graphs. These will show the system's performance under various conditions and will provide a basis for the development of a model that can predict the system's behavior. The study will also include a discussion of the limitations of the model and of the results of the tests.


## 1.2 Objectives

### 1.2.1 General Objectives

The general objectives of this study are to investigate the effects of various factors on the performance of a system and to develop a model that can predict the system's behavior. The specific objectives of the study are to determine the range of conditions over which the model is applicable and to determine the range of conditions over which the system's performance is acceptable.



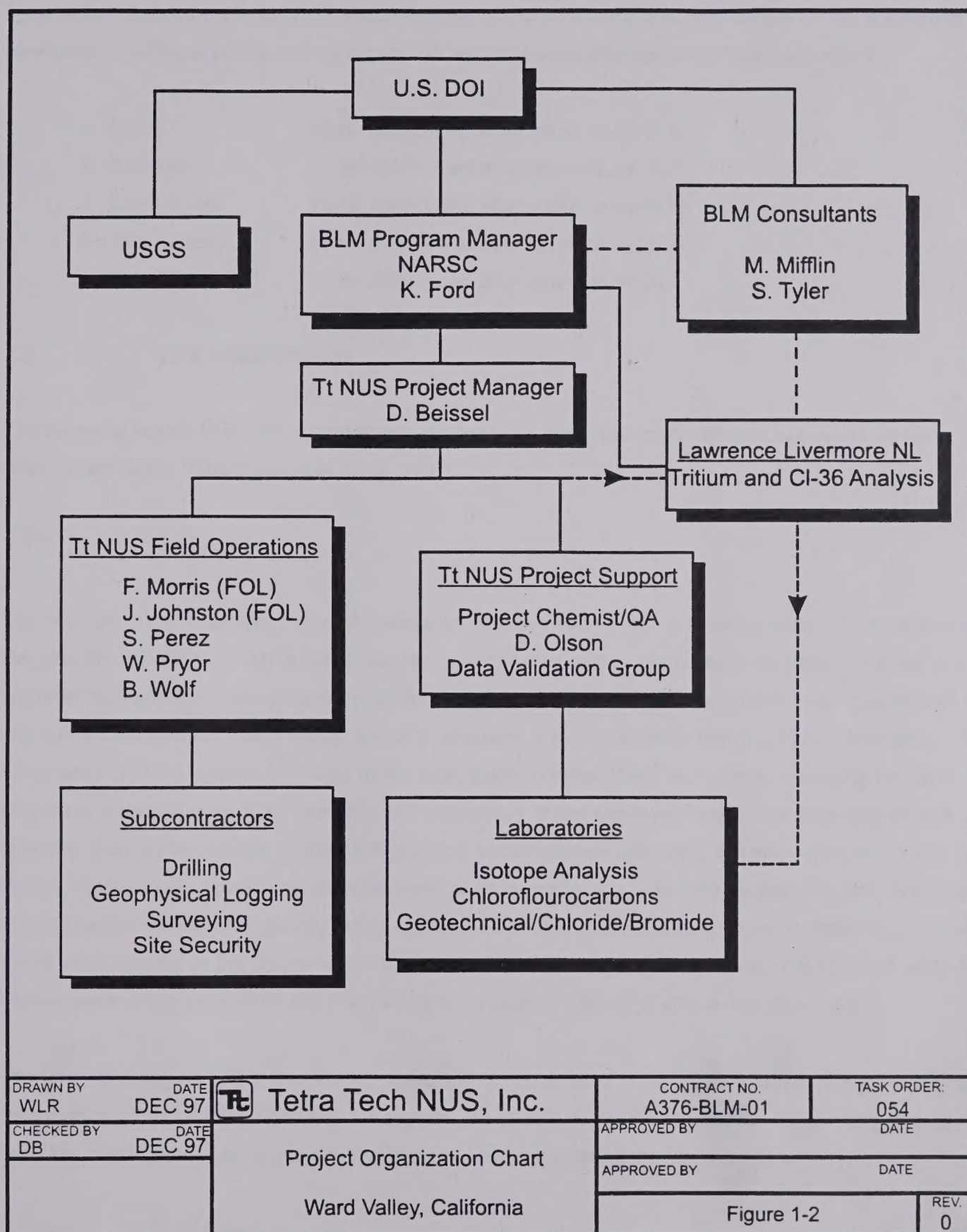


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SCALE  AS SHOWN		General Site Map  Ward Valley, California	APPROVED BY _____ DATE _____			
			Figure 1-1			









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Project Organization Chart

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Ward Valley, California

Figure 1-2

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### 1.2.2 Subcontractors

This section defines the roles and responsibilities of the subcontractors and names of key subcontractor personnel. Additional details will be included in the Contractor Management Plan, Appendix III.

- |                  |  |
|------------------|--|
| a. Driller       | To be determined after approval by DOI |
| b. Surveyor      | To be determined after approval by DOI |
| c. Laboratories  | To be determined after approval by DOI |
| d. Site Security | To be determined after approval by DOI |
| e. Suppliers     | To be determined after approval by DOI |

## 1.3 SITE DESCRIPTION

The following descriptions of the natural environment was summarized from the BLM Environmental Assessment of the Ward Valley site (BLM, 1997).

### 1.3.1 Geology

The location of the proposed low-level radioactive waste disposal site is in Ward Valley, California where the geology consists of alluvial fan deposits. Ward Valley trends north-south and the proposed site is bounded by the Sacramento Mountains on the east and the Piute Mountains on the west. The alluvial fan deposits in this area of Ward Valley are of Quaternary age and extend from the Piute Mountains. The topography of the proposed site dips to the east toward Homer Wash at a slope averaging two to three percent and ranges from 2,065 feet to 2,200 feet above mean sea level (msl). The youngest alluvial fan deposits occur at the surface and consist of poorly sorted gravels with weak soil development. The young alluvial deposits are underlain by older deposits of Pleistocene age. The Pleistocene deposits, comprised of moderately well-bedded gravel, sand, silt, and clay, are unconsolidated to moderately consolidated. Eagle peak located in the Sacramento Mountains to the east is at an elevation of 3,308 feet while the highest peak to the west of the site in the Piute Mountains is 3,560 feet above msl (BLM, 1997).

The Dead Mountain Fault is located approximately 13 miles east of the proposed site along the western portion of the Sacramento Mountains. However, the fault is partially buried under Quaternary alluvial fan deposits, therefore indicating that the displacement occurred before the fan deposition.





### 1.3.2 Hydrogeology

No perennial or intermittent surface water bodies exist near the proposed waste site. Precipitation drains through narrow (0.5 to 1 foot) ephemeral channels that cross the area. The drainage channels range in depth from 2 to 6 inches and appear approximately 50 to 75 feet away from each other on the east side of the site. Deeper channels appear on approximate 500 foot centers. Typically, alluvial fans show gully flow from runoff but here surface water appears to be primarily sheet flow during storms. The ephemeral channels appear to originate in the Piute Mountains to the west and discharge to Homer Wash to the east of the proposed site. Homer Wash drains to the south and is approximately 100 feet lower in elevation than the proposed site location. Homer Wash has two channels, one approximately 80 feet wide and four feet deep, and a smaller channel approximately 50 feet wide and three feet deep.

Runoff from the proposed site location enters Homer Wash where the drainage area is approximately 55 square miles. The area immediately upgradient of the site that drains into the wash is conservatively estimated at about 11 square miles (BLM, 1997). Interstate 40 north of the site is above grade and has its own drainage dikes and structures. The result of the highway is the routing of runoff from approximately 6 square miles into Homer Wash north of the proposed waste site. Storm runoff from the highway drainage structures has cut gullies into the ground up to 3 feet deep.

Groundwater in the area is present in north-northeast trending, elongated, alluvial filled basins. Some basins are closed and groundwater flows toward a dry lake while other basins discharge to an adjacent basin. Depth to groundwater is generally more than 500 feet below ground surface while groundwater beneath the proposed site is 690-695 feet (BLM, 1997). Groundwater in Ward Valley alluvium is rich in sodium bicarbonate (Miller, 1943) and groundwater development in Ward Valley has been limited. The dissolved solids concentration in the Danby Lake Basin to the south is greater than 10,000 milligrams per liter. The nearest well to the proposed site was abandoned in 1968 and was located at Camino, approximately 0.9 mile away.

### 1.3.3 Climatology

Ward Valley averages approximately 3 to 6 inches of precipitation per year. The nearby mountains receive less than 10 inches of precipitation per year. Groundwater storage is in the valley alluvium and is primarily derived from runoff from the mountains. Currently, it is believed that precipitation recharge

# Introduction

The purpose of this study is to investigate the effects of various factors on the growth of a specific plant species. The study was conducted over a period of six months, during which time the plants were grown under different conditions. The results of the study are presented in the following sections.

The first section of the study describes the experimental setup, including the selection of the plant species, the growth conditions, and the methods used to measure growth. The second section presents the results of the study, showing the growth of the plants under different conditions.

The third section discusses the implications of the study, showing how the results can be used to improve the growth of the plant species. The fourth section concludes the study, summarizing the findings and suggesting areas for further research.

## Conclusion

The study has shown that the growth of the plant species is affected by various factors, including light, temperature, and water. The results of the study can be used to improve the growth of the plant species in the future.



occurs high on the alluvial fans adjacent to the mountains and may be as low as 3 percent of total annual precipitation. Evaporation potential at Ward Valley may be as high as 98 inches per year which greatly limits infiltration of runoff.

#### 1.3.4 Ecology

Mojave Creosote Bush Scrub dominated by creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) comprise the vegetation in Ward Valley (Holland, 1986). The mean absolute cover at the site for the two species is 10.9 percent and 16.7 percent respectively. Common plant species associated with the site include white ratany (*Krameria grayi*), pencil cholla (*Opuntia ramosissima*), goldenhead (*Acamptopappus sphaeracephalus*), and buckwheat (*Eriogonum fasciculatum*). Scattered occasional plant species include Mojave yucca (*Yucca schidigera*) and big galleta grass (*Pleuraphis ridida*). Plant cover ranges from 31.1 to 37.0 percent. Homer Wash is dominated by Mojave Wash Scrub dominated by the species catclaw acacia (*Acacia greggii*). Other common species in Homer Wash include the smoke tree (*Psoralea arguta*) and ironwood (*Olneya tesota*). Cheesebush (*Hymenoclea salsola*), desert senna (*Senna armata*), ajamete (*Asclepias subulata*), and paperbug bush (*Salazaria mexicana*) are common understory species of Homer Wash.

Hedgehog cactus (*Echinocactus engelmannii* var. *howei*), crucifixion thorn (*Castela emoryi*), and physalis (*Physalis lobata*) were sought in surveys prior to the environmental assessment. None of the special plant species were found within a three-mile zone to be surveyed in the current investigations (US Ecology, 1989).

Wildlife at the proposed site are typical of the Mojave Creosote Bush Scrub community. The little pocket mouse (*Perognathus longimembris*), Merriam's kangaroo rat (*Dipodomys m. merriami*), antelope ground squirrel (*Ammospermophilus leucurus*), and desert woodrat (*Neotoma lepida*) are rodents commonly found in the region. Larger mammals include black-tailed hare (*Lepus Californica*), desert kit fox (*Vulpes macrotis*), badger (*Taxidea taxus*), and occasional coyotes (*Canis latrans*). Common birds in the area are the black-throated sparrow (*Amphispiza bilineata*), LeConte's thrasher (*Toxostoma lecontei*), loggerhead shrike (*Lanius ludovicianus*), cactus wren (*Campylorhynchus brunneicapillus*), ash-throated flycatcher (*Myiarchus cinerascens*), and mourning dove (*Zenaidura macroura*); Homer Wash is host to Gambel's quail (*Colipectes gambelii*). Occasionally present at or near the site are the Common raven (*Corvus corax*), red-tailed hawk (*Buteo jamaicensis*), prairie falcon (*Falco mexicanus*), and American kestrel (*Falco sparverius*). Common reptiles include the desert tortoise (*Gopherus agassizii*), side-blotched lizard (*Uta stansburiana*), western whiptail (*Cnemidophorus tigris*), leopard lizard (*Gambelia wislizenii*), desert iguana (*Dipsosaurus dorsalis*), zebra-tailed lizard (*Callisaurus draconoides*), desert horned lizard (*Phrynosoma*





platyrhinos), gopher snake (*Pituophis melanoleucus*) sidewinder (*Crotalus cerustes*), Mojave green rattlesnake (*C. scutulatus*), and Red Racer (*Masticophis flagellum piceus*); western patchnosed (*Salvadora hexalepis*), night snake (*Hypsiglena torquata*) and spotted leaf-nosed snake (*Phyllorhynchus decuracus*) have been occasionally observed.

The desert tortoise is a state and federally-listed "threatened" species. The site is located within the Piute-Fenner-Chemehuevi valleys tortoise population and both the Chemehuevi Critical Habitat Unit (USFWS, 1995) and the Chemehuevi Desert Wildlife Management Area inside the Eastern Mojave Recovery Unit (USFWS, 1995).

No vertebrate species known to use the site, even transiently, are state or federally-listed according to the California or Federal Endangered Species Acts. There are five birds in the area of the site that are considered California Species of Concern: prairie falcon, northern barrier, golden eagle, sharp-shinned hawk, and black-tailed gnatcatcher. None of the birds are known to nest at the proposed site and only 3 have been observed at the site, rarely. The black-tailed gnatcatcher is found in Homer Wash and LeConte's thrasher was formerly Category 2, but is now a "watch" species following the dissolution of the Category 2 division by USDI.

#### 1.4 SITE SECURITY AND LOGISTICS

Personnel working at the site will be advised of security issues arising from unauthorized persons present at the site and potential vandalism. On-going security issues will be discussed with project personnel at the beginning of each day's work, and proposed solutions discussed per the Site Security Plan (Appendix I).

##### 1.4.1 Temporary Structures/Fencing

A work compound, approximately 100 feet by 100 feet, will be established within Area 06 (existing cleared area between WV-MW-1&2) at a location designated by the TtNUS field operations leader (FOL) and approved by the BLM. An office trailer and portable sanitary facilities will be located in the area, and all equipment, materials, drill rigs, and similar items that require a higher level of protection will be stored in the compound area when not in use.

The perimeter of the work compound will be fenced with an eight foot high chain-link type fence to prevent unauthorized entry of personnel. The FOL and key personnel will maintain control of access to the compound through a single gate that will be secured by a chain and padlock when personnel are not present. The equipment steam cleaning area will be located downslope just offsite (east of the main





1 north-south road near Interstate 40) at a specific site approved by BLM. Drum storage for cuttings will be  
2 located within the 100' X 100' compound.

3  
4 **1.4.2           Guards and Lighting**

5  
6 As an added precaution, uniformed security guards will be present on a 24 hours per day basis to patrol  
7 the work compound and investigation areas. Security guards will not be armed, but will be authorized to  
8 stop and remove unauthorized persons, and patrol all relevant areas of the site. Security guards will be  
9 equipped with two-way radios or cellular phones to report disturbances or unusual occurrences to the FOL  
10 and appropriate law enforcement authorities. One guard will be deployed for day shift and one guard for  
11 night shift.

12  
13 The office trailer will be equipped with mercury vapor lighting that will illuminate the work compound area  
14 at night. This will assist the security guard in identifying evidence of any unusual activities or vandalism by  
15 individuals.





## **2.0 DATA QUALITY OBJECTIVES AND PROJECT QUALITY ASSURANCE**

The purpose of this Section is to address the Data Quality Objectives and quality assurance processes and procedures which will be applied to the project.

### **2.1 DATA QUALITY OBJECTIVES**

The data generated for this project will be used to further define the nature of water movement in the unsaturated (vadose) zone beneath the proposed Ward Valley low-level radioactive waste disposal site. Analytical data will be generated from the collection and analysis of soil gas, soil gas condensate, sediment core, shallow soil, groundwater, rain water, and well development water samples. Both geotechnical and isotope analytical data will be generated using approved ASTM, USEPA, and laboratory specific quality assurance procedures. The geotechnical analyses will be conducted in accordance with ASTM methodologies with the exception of the soil water bromide and chloride analyses which will be conducted in accordance with EPA SW-846 ion chromatography methodologies and the water potential analysis which will be conducted in accordance with the methodology listed in Section 6.1 (Note: all required analytical methodologies are presented in Section 6.0 and copies of the analytical methods are included in Attachment VI). The isotope analyses will be conducted in accordance with the procedures listed in Section 6.1 and the instrument detection limits must meet the practical quantitation limits listed in the analytical method.

### **2.2 PROJECT QUALITY ASSURANCE**

Project quality assurance is structured in accordance with applicable BRE Standard Operating Procedures (SOPs) and the guidance presented in the TtNUS Gaithersburg, Maryland Quality Assurance Manual. Specific protocols and requirements associated with project quality assurance are discussed below:

- Sample Collection Methods - All sample collection procedures as well as sampling equipment cleaning procedures and field measurements for the project are discussed in Section 4.0 of this Work Plan.
- Sample Handling - Sample handling procedures including field documentation, sample nomenclature, sample preservation, sample packaging and shipping, sample splits, and sample storage/archives are discussed in Section 5.0 of this Work Plan.





1 • Analytical Methods - Both geotechnical and isotope analytical methods will be employed at fixed-base  
2 laboratories to generate data for the Ward Valley project. These methods, along with their associated  
3 internal laboratory QA protocols, are discussed in Section 6.0 of this Work Plan.

4  
5 • Representativeness - Representativeness is an expression of the degree to which the data accurately  
6 and precisely depict the actual characteristics of a population or environmental condition existing at an  
7 individual sampling point. For this project the use of standardized sampling, handling, analytical and  
8 reporting procedures are designed so the final data derived are accurate representations of actual site  
9 conditions. During development of the sampling network for this project consideration was given to  
10 existing site characterization data and physical setting. The rationale of the sampling network is  
11 discussed in detail in Section 3.0 of this Work Plan.

12  
13 Representativeness in the laboratory will be ensured by using the proper analytical procedures and by  
14 meeting sample holding times.

15  
16 • Comparability - Comparability is defined as the confidence with which one data set can be compared  
17 to another (e.g., between sampling points; between sampling events). Comparability is achieved by  
18 using standardized sampling and analysis methods and data reporting formats including the use of  
19 consistent units of measure.

20  
21 Comparability of field data is dependent upon the proper design of the sampling program and will be  
22 satisfied by ensuring that this work plan is followed. It is also dependent on recording field  
23 measurements using the correct units. Field measurement units are further discussed in Section 4.7  
24 of this Work Plan.

25  
26 Planned laboratory analytical data will be comparable when similar analytical methods are used and  
27 documented. Results will be reported in units that ensure comparability with previous data.  
28 Laboratory measurement units are presented in Section 6.0 of this Work Plan.





- Completeness - Completeness is a measure of the amount of usable, valid, analytical data obtained, compared to the amount expected to be obtained. Completeness is typically expressed as a percentage using the following equation:

$$\text{completeness (\%)} = \frac{\text{number of validate points}}{\text{number of planned data points}} \times 100$$

The ideal objective for completeness is 100 percent (i.e., every sample planned to be collected is collected; every sample submitted for analysis yields valid data). Realistically, however, samples can be rendered unusable during shipping or preparation (e.g., bottles broken or extracts accidentally destroyed) and errors can be introduced during analysis (e.g., loss of instrument sensitivity; introduction of ambient laboratory contamination). These instances result in data that do not meet QC criteria. Based on these considerations, 90 percent is an acceptable expression of a project's data completeness objective. If critical data points are lost as a result of the preceding (or other) considerations, the resampling and/or reanalysis may be required.

One hundred percent of the laboratory data for this project will be validated. Data rejected as a result of the data validation process will be treated as incomplete data.

- Bottleware Requirements - The type of bottleware required to support a particular analysis is contingent upon the analytical method used and the matrix of the sample collected. General guidelines regarding bottleware requirements are contained in 40 CFR 136 (Guidelines for establishing Test Procedures for the Analysis of Pollutants; September 1992). Bottleware requirements for this project are presented in Section 6.0 of this Work Plan. If pre-cleaned bottleware is supplied by a commercial vendor, certification of bottleware cleanliness must be provided.
- Technical Holding Time Allowances - Maximum technical holding time allowances are established in 40 CFR 136 and vary with the matrix analyzed and method of analysis performed. Holding times are specified for both extraction (preparation), where applicable, and analysis. Technical holding time analyses are discussed in Section 6.0 of this Work Plan. Maximum technical holding times will be strictly observed so as not to diminish the sample's integrity through degradation or constituent loss.
- Data Evaluation and Reporting - Data transmitted, laboratory data validation, and data reporting are addressed in Section 7.0 of this Work Plan.

1. The first step in the process of the scientific method is to make an observation or ask a question. This is often based on something you have noticed or a problem you want to solve.

2. Next, you do background research to see what others have already discovered about the topic. This helps you to understand the current state of knowledge and to identify any gaps or areas for further investigation.

3. Then, you formulate a hypothesis, which is a statement that can be tested. It is often based on your observations and background research. You then design an experiment to test your hypothesis. This involves making a prediction about what you expect to happen and then carrying out the experiment to see if your prediction is correct.

4. After you have completed your experiment, you analyze the data and draw a conclusion. This is where you decide whether your hypothesis was supported or not. If it was supported, you may have found a new piece of evidence. If it was not supported, you may need to revise your hypothesis and try again.

5. Finally, you communicate your results to others. This can be done by writing a paper, giving a presentation, or sharing your findings with your classmates. This is an important part of the scientific process because it allows others to see your work and to build on it. They can also point out any mistakes or suggest improvements.

6. The scientific method is a systematic way of investigating the natural world. It helps us to understand how things work and to solve problems. It is used in many different fields, including biology, chemistry, physics, and earth science.

7. It is important to remember that the scientific method is not a straight line. Sometimes you may need to go back to an earlier step, such as making a new hypothesis or designing a new experiment. This is part of the process of learning and discovery.



1 • Technical Deliverable Review - All technical reviews will be approved in accordance with the  
2 provisions of TtNUS's Gaithersburg, Maryland office Quality Assurance Manual procedure  
3 10.1 (Procedure for Quality Verification of Reports/Analyses) prior to submittal to the client. This  
4 review will be documented and returned as part of the project QA record.

5  
6 • Other QA Considerations: Split samples will be generated for soil gas, soil, and aqueous matrices,  
7 and analyzed for tritium. The precision of the split sample data will be expressed as a Relative Percent  
8 Difference (RPD), which is a relation of the range relative to the mean expressed as a percent.

9  
10 The accuracy of the soil water chloride and bromide data will be evaluated using the percent recovery  
11 (%R) data generated by the laboratory. The %R data will be evaluated using the acceptance criteria  
12 presented in the analytical method (EPA 300.0). Accuracy for the isotope analyses will involve evaluating  
13 the laboratory internal QA samples which consist of blanks, blinds, and crosscheck samples. This will be  
14 done during data validation.

15  
16 All hardcopy and electronic data generated during the course of the investigation will be maintained by  
17 TtNUS in the Bureau of Land Management (BLM) central files located in Gaithersburg, Maryland. Upon  
18 completion of the contract, all files will be relinquished to BLM.

1. The first part of the report deals with the general situation of the country and the results of the survey. It is divided into two sections: the first section deals with the general situation of the country and the second section deals with the results of the survey.

2. The second part of the report deals with the results of the survey. It is divided into two sections: the first section deals with the results of the survey and the second section deals with the results of the survey.

3. The third part of the report deals with the results of the survey. It is divided into two sections: the first section deals with the results of the survey and the second section deals with the results of the survey.

4. The fourth part of the report deals with the results of the survey. It is divided into two sections: the first section deals with the results of the survey and the second section deals with the results of the survey.



### 3.0 SITE CHARACTERIZATION STRATEGY

#### 3.1 VADOSE ZONE

The specific objective of the vadose zone investigation is to assess the vertical distribution and relative trends of selected analytical parameters from the unsaturated zone for evaluation of hydrological mechanisms for water movement below the proposed site. The parameters used for this evaluation consist of tritium (previously reported in 3 monitoring boreholes), chlorine-36, deuterium, and oxygen-18. The radioisotopes (tritium and chlorine-36) are considered tracers associated with nuclear weapons testing in the 1950s and 1960s. Along with the stable isotopes (deuterium and oxygen-18) their vertical distribution in the vadose zone signifies depth of infiltration (recharge) of "modern" water and enables the determination of source areas and potential mixing patterns.

Data will be obtained from a series of deep and shallow boreholes along with samples from near surface trenches in both interfluvial and ephemeral wash zones. Success of the vadose zone sampling relies upon a sufficient volume of moisture being extracted from sediment cores and soil vapor/condensate being collected from multi-level gas ports.

##### 3.1.1 Sediment Cores

In addition to attempting to resample the locations where tritium was previously detected, this phase of the investigation will also provide isotopic data from deeper sediment (>30 meter). The investigation will be accomplished by installing five 150 foot boreholes. Each borehole will be continuously cored from the land surface to a depth of 100 feet below ground surface (bgs). Five foot core lengths will be collected at 10 foot intervals from 100 to 150 feet bgs.

Two 700 foot borings will also be continuously cored from the ground surface to a depth of 100 feet bgs. Five foot cores will then be collected on 40 foot intervals from 100 feet bgs to 10 feet above the water table. Each 5-foot section of core will be contained in subdivided brass sleeve tubing and housed according to protocols described in the remaining sections of this plan.

In the event that a greater volume of sediment core is needed for tritium extraction, drill cuttings will be sampled from each cored interval and sent to the lab as potential substitute material for chloride, Cl-36, and bromide analyses.





## 3.1.2

Soil Gas

After coring operations, seven of the boreholes will be retrofitted with either five or eight stainless steel soil gas ports depending on total depth. Placement of the soil gas ports will be comparable to depths of those already in existing boreholes (less than 100 feet deep). Deeper soil gas ports will be set at farther spaced intervals at depths corresponding to anomalous moisture zones. Geophysical logging with gamma-gamma, natural gamma, and neutron tools will be conducted, if practical (little or no casing/drill pipe interference). These logs can be run in conjunction with the inclinometer survey designed to acquire precise target depths in the deep borings. The neutron tools could potentially define anomalously high moisture zones suitable for placement of gas ports.

The objectives of the Ward Valley soil gas sampling activities are to establish which of the generalized process scenarios (for unsaturated water percolation and infiltration) are occurring under natural conditions at the site. The soil gas (condensate) sampling and analysis for tritium will establish what recharge mechanisms, if any, are occurring at the site. Modern atmospheric water vapor is enriched in tritium as a result of the atmospheric nuclear testing conducted in the 1950s and early 1960s. If modern precipitation is recharging the aquifer beneath the site, detectable levels of tritium should be present in soil gas condensate samples collected from the vadose zone. The collection of soil gas condensate samples from multiple depths will define the depth to which modern precipitation infiltrates the subsurface.

The intrusive nature of the proposed drilling and borehole completion methods may introduce atmospheric air to the samples and the subsurface. In theory, after purging the soil vapor extraction ports, atmospheric air will be eliminated from the subsurface and soil gas samples will be representative of in-situ conditions. A tracer (sulfur hexafluoride) will be used to test the potential for infiltration of drilling air into the formation. Soil gas condensate sampling allows for comparative tritium analyses to be performed at the same depths intervals where soil core water samples have been obtained. Soil vapor extraction ports can also provide continual monitoring of the variable hydrologic processes typical in arid regions such as the Ward Valley site. Soil gas condensate sampling may be used in predicting and monitoring the hydrologic responses during construction and operation of the facility. Continual monitoring of the vadose zone through soil gas (condensate) sampling can also provide improved understanding the site's performance during facility operations.





### 3.1.3 Near Surface Sampling

A near surface sampling program will be conducted to compare the depth of penetration of infiltration and recent atmospheric tracers (chloride and chlorine-36) in interfluvial and small ephemeral wash settings as are found at the site. The position and distribution of these tracers will provide specific information on the nature of infiltration from ephemeral washes at the site. The near surface sampling program will consist of one or possibly two, 2 m deep trenches dug perpendicular (north-south) to an observed active wash channel. The trenching program will encompass both an interfluvial zone and ephemeral wash to investigate the differences in infiltration across these two environments. It may be practical to construct two adjacent trenches rather than a single trench to sample to accomplish this objective. The setting of the trenches should be used to determine if one or two trenches are appropriate to characterize channels and interfluvial environments. The trench is anticipated to be at least 8 meter in length, or two 4 m by 2 m trenches to accomplish this phase of the sampling.

In addition, a series of ten shallow (approx. 6 m) hollow stem auger (HAS) corings are proposed in fluvial/interfluvial setting. These sediment cores will provide an inexpensive and effective approach to obtain slightly deeper chloride and chlorine-36 distributions in the near surface environments. The auger borings and trench(s) will be constructed and sampled according to Sections 4.6 and 4.7 of this plan, respectively.

### 3.2 SATURATED ZONE

The groundwater investigation will provide analytical data from the capillary fringe to the water-table. The investigation will be accomplished by installing two monitoring wells to depths of approximately 720 feet. Continuous sediment core samples similar to those described above will be collected from 10 feet above the saturated zone to ten feet below the water table. Pore water samples will be analyzed from the cores through the capillary fringe, and groundwater samples will be collected from near the top of the saturated zone. To determine an accurate depth to the water table prior to drilling at the GB-06 Site, borehole inclinometer surveys must be completed WV-MW-01/02 prior to drilling and an accurate depth to water obtained from the GB-06 Site. At the GB-04 Site, well site elevation combined with established water table elevations are to be used to predict the water-table depth.

A borehole inclinometer survey is also to be made in each deep borehole when the drilling depth is within 50-100' of the anticipated water table-depth to calculate the drilling depth. The inclinometer (Century Geophysical 9095 logging tool) is also capable of simultaneously recording natural gamma through steel drill rods. When drilling depth is within 10' of the water table depth, continuous coring is to be initiated and





proceed to 10' below the anticipated water table depth. Drilling is to cease at this depth, with at least 24 hours passing before a water level measurement is made to allow reestablishment of the water level and confirmation that the saturated zone has been penetrated. Grab samples of groundwater during drilling operations will be attempted to assist in the assessment of potential stratification of parameters of interest. The water level measurement and sampling may be best accomplished through the drill pipe or outer casing depending upon drilling method employed. Geophysical logging with gamma-gamma and neutron tools will also be made prior to borehole completion, if practical.

Groundwater samples will be collected from the uppermost water-table zone in both new and existing wells for tritium, chlorine-36, stable isotopic analysis and carbon-14. Sampling methodology will be determined by the transmissivity of the aquifer. The sampling method(s) will be designed to sample representative water from the uppermost water in the aquifer.

If the facility becomes operational, the boreholes may be used for long-term monitoring of groundwater processes and provide additional data of site performance during operations.

### **3.3 RAINWATER**

The objective of collecting rainwater, if it occurs during the field investigation, is to have a background blank for baseline comparison to groundwater beneath the proposed site location. Rainwater will be collected during the first rain event and the water will be analyzed for the same parameters as the groundwater.





## **4.0 FIELD OPERATIONS AND SAMPLE COLLECTION METHODS**

### **4.1 GENERAL FIELD OPERATIONS**

#### **4.1.1 Mobilization/Demobilization**

The Field Operation Leader (FOL) will coordinate the mobilization activities prior to the initiation of field work. These activities will include coordinating with BLM personnel and the various subcontractors, confirming that all UXO has been removed from the field activity area, purchasing expendable equipment, decontaminating field equipment, and preparing the field trailer. The majority of the health and safety equipment required for the field activities will be shipped from the TtNUS Gaithersburg office to the site. After field activities are completed, the FOL will demobilize the equipment.

### **4.2 SUBSURFACE INVESTIGATIONS**

#### **4.2.1 Shallow Soil Borings**

A total of 5 soil borings [WV-GB04 (SG-02), WV-GB01 (SG-03), WV-GB01 (SG-04), WV-GB01 (SG-05), and WV-GB06 (SG-06)] will be completed to a depth of 150 feet using dual or triple-wall air rotary drilling for shallow sediment vapor monitoring as shown on Figure 4-1. The drilling and sampling equipment will be free of any sources of tritium, chlorine-36, chloride, and bromide beyond that naturally found in the environment. To ensure this, all downhole equipment will be steam cleaned and dried prior to commencement of drilling activities. In addition, all sampling equipment will be thoroughly cleaned between sampling sites as detailed in Section 4.10. All pertinent field data will be recorded in the field log book.

#### **4.2.2 Deep Soil Borings**

The two soil borings [WV-GB04 (SG-01) and WV-GB06 (SG-07)] associated with both the deep sediment vapor sampling and monitoring well installations will be completed using dual or triple-wall air rotary drilling methods. The same requirements stated in Section 4.2.1 will be met for the drilling of these deep boreholes. No fluids other than dried and filtered air are to be used in the drilling and coring process. The sediment vapor ports will be attached to the outside of the 2 inch ID steel monitoring well riser.











### 4.2.3 Sediment Core Sample Collection

Samples collected during drilling operations will be obtained with 12" brass sleeve segments lining a solid tube sampler in accordance with ASTM methodologies D 3550-84, D 4700-91, and D 1587-83 (Appendix V). Sediment core samples will be collected using 5-foot long, minimum 3.5-inch ID solid drive sample tubes of hardened steel. However, sample recovery may be difficult to maintain at depth using the solid sample tube due to some coarse unconsolidated sediments which are anticipated at the site. In such an event, the split spoon sampling method (ASTM D 2686-84) with brass sleeve liners will be used. The split-spoon sampler will be driven to the required depth either by means of a drill rig mounted hammer weighing 300 pounds for a 30-inch fall or a percussion hammer. The split-spoon will be a minimum 2 feet and maximum 5 feet in length and at least 3.5 inches inside diameter. The shorter recovery length will require an increase in the number of core samples collected, however, the number of samples for analysis will not increase since the samples will be distributed in the same manner as the solid tube sampler per their depth within a 5 foot interval. The distribution for analysis is discussed in Section 4.2.5. The shallow boreholes will be sampled with continuous coring to 100 feet and 5 foot cores at 10 foot intervals from 105 to 150 feet.

The 2 deep boreholes to be converted to monitoring wells will be continuously cored from ground surface to a depth of 100 feet and on 40 foot intervals from 100 feet below ground surface (bgs) to 10 feet above the water table. Continuous coring will be continued to 10 feet below the water table. The actual sample depth intervals will be determined by the field geologist based on site-specific observations and sample recovery. Table 4-1 shows the total number of samples per borehole. Since sample recovery in the deep borings may be difficult, there is a contingency plan for sample distribution discussed in Section 4.2.5.

### 4.2.4 Soil Sample Handling

Once the solid drive or split-barrel is removed from the borehole and opened with wrenches, the core will be transferred to an enclosed area for sample processing. The 12 inch brass sleeves will be removed from the split barrel, sealed with Teflon™ inserts, covered with plastic end caps, and taped. Each brass sleeve will be clearly marked with sample identification, depth, time, and orientation of core top using indelible marking ink. Each brass sleeve will then be placed in a sealed plastic or mylar bag and clearly marked with sample identification and depth. Depending on the sampling method used, any soil from the leading edge of the core (often termed "nosecone sample") will be removed prior to core extraction. This material will be placed immediately in a sealed plastic or mylar bag and clearly marked with sample identification, depth, and notation indicating that it is the first sample of the core. Sample handling procedures will be in accordance with ASTM D 4220-89 (Appendix V).







**TABLE 4-1**  
**SUMMARY OF FIELD AND ANALYTICAL PROGRAM**  
**WARD VALLEY SITE EVALUATION**  
**WARD VALLEY, CALIFORNIA**

Sample Type	Sample Description	Number of Borings/ Excavations	Number of Samples per Borehole <sup>(2)</sup>	Total Number of Samples	LLNL Analytes	Number of Samples to be sent to LLNL	TtNUS Lab Analytes	Number of Samples to be sent to TtNUS Lab
Sediment Cores	Shallow Boreholes	5	25	125	Tritium, Cl-36	125	Oxygen-18, deuterium, geotechnical parameters <sup>(1)</sup>	125
	Deep Boreholes	2	37	76	Tritium, Cl-36	76	Oxygen-18, deuterium, geotechnical parameters <sup>(1)</sup>	76
	Hollow Stem Auger	10	4	40	Cl-36	40	Geotechnical parameters <sup>(1)</sup>	40
	Trenches	1 or 2	3 x 15	45	Cl-36		Geotechnical parameters <sup>(1)</sup>	45
	Blanks	7	3	21	Tritium, Cl-36	21	Oxygen-18, deuterium,	21
	Splits	5% x 2 labs		26	Tritium	NA	Tritium	22
Aqueous	BLM Wells <sup>(3)</sup>	2	2	4	Tritium, Cl-36	4	Carbon-14, Oxygen-18, deuterium	4
	US Ecology Wells	3	1	3	Tritium, Cl-36	3	Carbon-14, Oxygen-18, deuterium	3
	Rainwater	1	1	1	Tritium, Cl-36	1	Carbon-14, Oxygen-18, deuterium	1
	Splits	1 x 2 labs		2	Tritium	0	Tritium	2
Sediment Vapor/Condensate	Shallow Boreholes	5	8	40	Tritium	40	CFC's	40
	Deep Boreholes	2	5	10	Tritium	10	CFC	10
	US Ecology Sample	3	4	12	Tritium	12	CFC	12
	Air Blanks	1	1/wk	12	Tritium	12	CFC	12
	Lab Blanks	5%		6	Tritium	6	CFC	6
	Splits	5% x 2 labs		8	Tritium	0	Tritium	8

<sup>(1)</sup> Geotechnical parameters include water potential, particle size analyses, bulk density, chloride, and bromide.

<sup>(2)</sup> Assumes use of 5' sampling tube with 100% recovery from boreholes.

<sup>(3)</sup> Includes grab sample during drilling operations.





Core blanks will be prepared to provide procedural blanks for tritium. Blanks will be prepared by LLNL using clean, washed, oven-dried sand. Approximately 50 ml tritium-free water from LLNL will be added to the sand following drying and packed into 12 inch brass sleeves identical to those used in the field. The cores will be sealed as per the core handling requirements mentioned in the preceding paragraph.

In the field, at least two core blanks per borehole are to be opened during shallow drilling operations and handled in a similar fashion to cores recovered during drilling. The cores are to be exposed to the atmosphere for similar times as needed for actual core handling then resealed using the same procedures as drill cores. The blanks will be recorded with sample identification numbers, stored and shipped along with drill cores to the appropriate analytical laboratory(s).

Drill cuttings obtained from a cyclone separator are to be collected in plastic bags during each core sample run. One 1 liter bagged sample will be sent to LLNL for CI-36 analysis. The remaining cuttings will be bagged, labeled, and drummed for later use or disposal.

#### **4.2.5            Soil Sample Distribution**

All core samples are to be stored in a secure sampling trailer onsite prior to shipping for laboratory analysis. Table 4-1 shows the number of samples to be collected per borehole, sample analyses, and distribution to the appropriate laboratory. The following lists the core segment priorities from the bottom of the core interval upward for analysis:

Nosecone sample: Water potential (ASA Method - 26.1), Gravimetric Water Content (ASTM D2216-92).

First 12-inch Brass Sleeve: Tritium. (If additional sample volume is needed for tritium analysis due to low water content, the next core section (2nd brass sleeve) will also be used. In this case, the remaining brass sleeves are to be used in the same order as below. This will also be the case when split samples are collected. A description of splitting procedures is described in Section 5.5 Quality Control Samples.)

Second 12-inch Brass Sleeve: Tritium and chlorine-36 (Note that drill cutting samples from the interval may be substituted for some of the chloride (Cl-36, bromide analyses).

Third 12-inch Brass Sleeve: Oxygen-18, and deuterium

Fourth 12-inch Brass Sleeve: Soil water chloride and bromide by colormetrics, gravimetric water content, dry bulk density, and particle size analysis, and water potential.

The first part of the paper is devoted to a general discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the atom. The second part is devoted to a detailed discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the atom.

The third part of the paper is devoted to a detailed discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the atom. The fourth part is devoted to a detailed discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the atom.

The fifth part of the paper is devoted to a detailed discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the atom. The sixth part is devoted to a detailed discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the atom.

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Fifth 12-inch Brass Sleeve: Archive or used for split samples (5%).

If there is a problem with poor core recovery or when split samples are required, all core samples will be distributed for the necessary analyses and will not be archived. Tritium analysis will be the first priority.

### **4.3 MONITORING WELL CONSTRUCTION, INSTALLATION AND SAMPLING**

#### **4.3.1 Monitoring Well Construction and Installation (Dual or Triple-Wall Air Rotary Drilling Method)**

Two deep (720') soil borings [WV-GB04 (SG-01) and WV-GB06 (SG-07)] will also be completed as 2-inch ID stainless steel monitoring wells. The monitoring wells will be designated WV-GB04 (MW06) and WV-GB06 (GW07), respectively. The sediment vapor ports, described in Section 4.4, will be attached to the outside of the 2-inch riser pipe as the well is installed. The boreholes will be drilled using dual or triple-wall air rotary techniques. Each borehole will be surveyed and tied to existing benchmarks. Survey accuracy will be achieved to within 0.01 foot vertical (elevation) and 0.1 foot horizontal (location). To determine an accurate depth to the water table prior to drilling at the GB-06 Site, borehole inclinometer surveys will be completed on existing monitoring wells WV-MW-01 and WV-MW-02 prior to drilling WV-GB06-GW-07.

The accuracy of the inclinometer (Century Geophysical 9095 logging tool) is +/- 0.5 degree (X-Y) tilt measurement with a gyro accuracy of +/- 5% or 2 degrees. This cased-hole tool is also capable of simultaneously recording natural gamma through steel drill rods. The digital solid state design uses a continuous reading gyroscope (Humphrey Inc., DG-69) with information recorded at any selected sample intervals without stopping to take station data. An accurate depth to water will be obtained for Site GB-06. If borehole inclinometer surveys can not be made on these existing wells, the depth to the water table is to be estimated from license application data. At the GB-01 Site, well site elevation combined with established water table elevations are to be used to predict the water table depth.

A borehole inclinometer survey will be also made in boreholes WV-GB04 (SG-01) and WV-GB06 (SG-07) when the drilling depth is within 50-100 feet of the anticipated watertable depth to calculate the exact drilling depth. When drilling depth is within 10 feet of the water table, continuous coring will be initiated and proceed to 10 feet below the anticipated water table depth. The borehole will be complete at this depth. Prior to installation of the monitoring well and at least 24 hours after drilling has been complete, a water level measurement will be made to ensure the accurate placement of the screened interval. A grab





sample of groundwater will be obtained as soon as the water table is reached. The grab sample will be sent for tritium, Cl-36, and C-14 analyses.

Both monitoring wells will be constructed of 2-inch ID stainless steel flush-joint screens and galvanized steel riser pipe. The top of the screened interval will be positioned approximately 10 feet above the stabilized water level. Screen lengths will be 20 feet and will have a screen slot size of both 0.010 inch and 0.020 inch available for installation. The TtNUS geologist will determine the screen slot size in the field based on the visual analysis of core samples and cuttings collected from the bottom 20-foot interval. After the boring is drilled to the desired depth, the well screen and riser pipe will be installed through the outer casing. Centralizers will be installed only immediately above and below the well screen.

A silica sand pack will be installed into the boring annulus around the well screen. The sand pack will be medium to coarse grained, well graded, silica sand such as Monterey 10/20. The sand pack will be installed from the bottom of the boring to approximately 3-5 feet above the top of the well screen. The sandpack will be installed by pouring the sand through a 2" minimum ID tremie pipe into the annular space between the riser pipe and the outer casing. The casing will be withdrawn from the boring as the sand is emplaced. The sand will always be kept within the casing during withdrawal to ensure an adequate sandpack. A weighted tape measure or tremie pipe tamping will be used during the installation to ensure that no bridging occurs and to maintain no more than 1 foot of sand above the bottom of the outer casing as it's retracted.

The depths of all backfill materials will be monitored during the well installation process by means of an accurate measuring device. A 100 percent sodium bentonite slurry seal, no less than 5 feet thick, will be installed above the sand pack. The bentonite slurry will be mixed using tritium-free water obtained from LLNL and will be installed using a tremie pipe, and allowed to cure prior to the placement of the filter and seal material for the sediment vapor ports. The monitoring well installation will be completed in accordance with the ATSM standard D 5092-90 and TtNUS SOP GH-1.7 (Appendices IV and V). The surface completion is discussed in Section 4.5.

#### **4.3.2 Water Level Measurement**

All groundwater monitoring wells (new and existing) depicted on the Site Map (Figure 4-1) will be monitored for water levels after the completion of the inclinometer survey. An electronic water level meter capable of 0.01 foot resolution will be used. The top of the well casing will be used as the reference point for determining depths to water. To ensure consistency between water level measurements, a permanent location will be marked at the top of the well casing. Water level measurements will be recorded to the nearest 0.01 foot in the appropriate field log book and on a groundwater level measurement form. All measurements will be collected in accordance with ASTM Method D 4750-87 and TtNUS SOP GH-1.2 within



The first of these is the fact that the system is not a simple one. It is a complex system, and the complexity is not only in the number of components, but also in the way they are interconnected. This complexity is what makes the system so interesting, and it is also what makes it so difficult to understand.

The second of these is the fact that the system is not a static one. It is a dynamic system, and the dynamics are not only in the way the components interact, but also in the way the system evolves over time. This dynamic nature is what makes the system so fascinating, and it is also what makes it so challenging to study.

The third of these is the fact that the system is not a closed one. It is an open system, and the openness is not only in the way the system interacts with its environment, but also in the way the system is influenced by its environment. This openness is what makes the system so complex, and it is also what makes it so difficult to model.

The fourth of these is the fact that the system is not a linear one. It is a non-linear system, and the non-linearity is not only in the way the components interact, but also in the way the system behaves. This non-linearity is what makes the system so unpredictable, and it is also what makes it so difficult to control.

### Why is this important?

The importance of this system lies in the fact that it is a model of a real-world system. It is a model of a system that is complex, dynamic, open, and non-linear. This model is what allows us to study the system, and it is what allows us to understand the system. It is this understanding that is what makes the system so important.



a 24-hour period. A licensed land surveyor will establish well locations and elevations prior to protective covers being installed.

#### **4.3.3            Monitoring Well Development**

Both of the newly installed groundwater monitoring wells will be developed in accordance with the procedures in TtNUS SOP GH-1.7. The monitoring wells will be developed by the drillers no sooner than 48 hours nor longer than 7 calendar days after the completion of the well installation. Bailing techniques will be used during well development. A minimum of 5 times the standing water volume in the well casing plus 5 times the water volume in the saturated sand pack (assume 30 % porosity) will be removed if possible. The wells will be developed until the discharge water is visibly clear; temperature, pH, and specific conductivity have stabilized to within 10% variance for three consecutive measurements; or as determined by the TtNUS field geologist. Turbidity will also be measured during well development; an attempt will be made to develop the well to a turbidity of 10 NTU. All water quality measurements and the volumes removed will be recorded for each well.

Development water will be collected in 55-gallon drums. At the completion of well development, development water will be released to the ground surface in the vicinity of the cleaning area as per Section 4.9.1.

#### **4.3.4            Field Measurements**

Field measurements will be taken during sampling operations and will include water quality (TtNUS SOP SF-1.1) including pH, specific conductance, temperature, and turbidity. Measurements will be recorded either in the site logbook or Sample Log Form. Instruments used in the field to record this data will be calibrated to the procedures described below.

##### **4.3.4.1            Equipment Calibration**

One or more of the following monitoring instruments may be used during field activities:

- Temperature probe
- Specific conductance meter
- pH meter
- Turbidity meter
- Electronic water-level indicator





Field instruments will be calibrated according to the manufacturer's procedures and per the following:

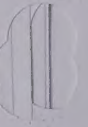
- The pH meters will be calibrated daily. At least two buffer solutions that bracket the expected sample pH will be used (e.g., 4.0 and 7.0) to calibrate pH meters.
- Specific conductance meters will be calibrated prior to each day's use.
- Thermometers will be calibrated monthly. The expected range of sample temperatures will be bracketed. This will be performed at the TtNUS equipment warehouse.
- Turbidity meters will be calibrated at least daily using a standard within the expected range of sample turbidities.
- Duplicate measurements of pH, specific conductance, temperature, and turbidity will be taken at a frequency of one in 10 samples and used to estimate the precision of the field analytical measurements.

Calibration will be documented on an Equipment Calibration Log (Appendix IV). During calibration, an appropriate maintenance check will be performed on each piece of equipment. If damaged or defective parts are identified during the maintenance check and it is determined that the damage could have an impact on the instrument's performance, the instrument will be removed from service until the defective parts are repaired or replaced.

#### **4.3.5            Groundwater Purging and Sampling**

##### **4.3.5.1            Groundwater Purging**

Prior to obtaining a groundwater sample, the water level in the monitoring well will be measured to within 0.01-foot accuracy from the marked location on the top of the well riser pipe. Both newly installed and existing monitoring wells will be purged prior to sample collection. Purging will be accomplished by removing groundwater from the well using a tritium-free, decontaminated Bennett™, low flow rate pump with a new, clean length of polyethylene tubing. Temperature, pH, turbidity, and conductivity measurements will be taken and recorded before, during (at least twice), and after purging the well in accordance with the discussion in Section 4.3.6. Purging will continue until field measurements collected by in-line instrumentation or standard sample collection methods for groundwater, have stabilized within 10% over at least two measurements, or until 3 well volumes are removed. The volume removed will be determined by the time and measured pump rate, or by direct measurement of the purged volume. These data will be recorded in the sampling log book





along with instrument calibration data. In the event that the aquifer recharge does not allow sustained pumping or does not return to 70% of original static water level after 2 hours, a decision may be made to sample the well prior to removal of 3 calculated well volumes. Purge water will be collected and disposed of in the same manner as development water as per Section 4.9.2.

#### **4.3.5.2 Groundwater Sampling**

Groundwater sampling will occur after a minimum of 14 days following well development of newly installed monitoring wells. If practical and possible, water samples are to be collected from the uppermost water-table zone for tritium, chlorine-36, stable isotopic analysis, and carbon-14. Sampling methodology will be determined by the transmissivity of the aquifer. The sampling method(s) must be designed to sample representative water from the uppermost water in the aquifer. All groundwater sampling will be conducted in accordance with the requirements of ASTM standard D 4448-85a and in accordance with TtNUS SOP SA-1.1, (Appendices IV and V).

Following the purging process, samples will be collected with a bailer or a Bennett™ piston pump. To avoid excessive oxidation or adsorption on the well casing, samples will be collected as soon as sufficient recharge occurs to raise the water level at least 5 feet above the lowest measured water level during purging. Table 4-1 shows the total number of samples and analyses per monitoring well. All well purge and sampling equipment will be thoroughly decontaminated between sampling sites as detailed in Section 4.8. All pertinent field data will be recorded on a well sample form (Appendix IV) and in the field log book.

#### **4.3.5.3 Rainwater Samples**

In the event of a rain event during the field effort, a sample of rainwater will be collected using a glass beaker. A 100 ml sample will be sent to LLNL and analyzed for tritium in order to get baseline data.

### **4.4 SEDIMENT GAS PORT CONSTRUCTION, INSTALLATION, AND SAMPLING**

#### **4.4.1 Sediment Gas Port Construction and Installation**

Nested sediment vapor extraction ports will be installed in the 5 shallow boreholes [WV-GB04 (SG-02), WV-GB01 (SG-03), WV-GB01 (SG-04), WV-GB01 (SG-05), and WV-GB06 (SG-06)] and the 2 deep boreholes [WV-GB04 (SG-01) and WV-GB06 (SG-07)]. Shallow boreholes will be drilled to approximately 150 feet bgs. Eight sediment vapor extraction ports will be installed at various depths comparable to those in existing boreholes within each new shallow borehole. Screened intervals will be centered at 145,





135, 125, 115, 100, 60, 35, and 20 feet bgs. Two deep boreholes will be drilled to approximately 720 feet bgs. Five sediment vapor extraction ports will be installed in each deep borehole. Screened intervals will be centered at 700, 585, 465, 345, and 185 feet bgs. Sediment vapor extraction port installation procedures and material specifications are described below:

- Each sediment vapor extraction port will consist of 21 inch x 0.25 inch ID stainless steel screen (commercially available) coupled to 0.25 inch outside diameter (OD) nylon riser tubing.
- To keep the vapor extraction ports centered and rigid within the 150 feet boreholes during installation, a one inch steel gas pipe will be used as a centering pipe. In the 750 feet deep boreholes, the 2 inch monitoring well riser will be used as the centering pipe. Vapor extraction ports will be fastened to the outside of the gas pipe every 10 feet (as they are lowered downhole) using stainless steel hose clamps. The gas pipe will extend approximately 1 foot beyond the deepest vapor well screen to support the weight of the nested vapor well assembly and protect the deepest vapor well screen from excessive downward pressure.
- Installation of the nested well assembly will begin with fastening the deepest sediment vapor extraction port to the gas pipe. The well screen will be fastened approximately 1 foot above the terminus of the gas pipe. The nylon riser tubing of each vapor extraction port will be provided in 1,000 feet rolls. As the gas pipe is lowered down hole, the riser tubing will be unrolled and fastened to the gas pipe at 10 foot intervals. Each successive (shallower) vapor extraction port will be connected to the gas pipe as its depth interval along the gas pipe is reached.
- A pipe clamp will be fabricated to secure the gas pipe as additional gas pipe sections are being attached and during attachment of sediment vapor extraction ports.
- Once the nested sediment vapor well assembly has been lowered into the borehole, the annular backfill materials will be installed. Four foot intervals of 8/12 silica sand will be tremied downhole to surround each soil vapor extraction port screen. Each screen will be centered in the 4 foot interval of 8/12 silica sand. Intervening intervals (including the bottom of the borehole to the deepest well screen) will be backfilled with a 60:20:20 mixture of 20/40 silica sand, silica flour (200 mesh), and bentonite powder. The upper 5 feet of the borehole annular space will be backfilled with cement.
- Each nylon riser tubing will be cut at approximately three feet above ground surface and fitted with a compression fitting and a label designating the extraction port's depth interval. A 12 inch diameter lockable well cover will be installed with a stick-up of approximately 3 feet above ground surface.

1. The first part of the report deals with the general situation of the country. It is a very interesting and informative study of the country's development and progress. The author has done a great deal of research and has presented the facts in a clear and concise manner. The report is well written and is a valuable contribution to the study of the country's development.

2. The second part of the report deals with the economic situation of the country. It is a very detailed and comprehensive study of the country's economy. The author has done a great deal of research and has presented the facts in a clear and concise manner. The report is well written and is a valuable contribution to the study of the country's economy.

3. The third part of the report deals with the social situation of the country. It is a very detailed and comprehensive study of the country's social conditions. The author has done a great deal of research and has presented the facts in a clear and concise manner. The report is well written and is a valuable contribution to the study of the country's social conditions.

4. The fourth part of the report deals with the political situation of the country. It is a very detailed and comprehensive study of the country's political conditions. The author has done a great deal of research and has presented the facts in a clear and concise manner. The report is well written and is a valuable contribution to the study of the country's political conditions.

5. The fifth part of the report deals with the cultural situation of the country. It is a very detailed and comprehensive study of the country's cultural conditions. The author has done a great deal of research and has presented the facts in a clear and concise manner. The report is well written and is a valuable contribution to the study of the country's cultural conditions.

6. The sixth part of the report deals with the future of the country. It is a very detailed and comprehensive study of the country's future prospects. The author has done a great deal of research and has presented the facts in a clear and concise manner. The report is well written and is a valuable contribution to the study of the country's future prospects.



#### 4.4.2 Sediment Vapor Sampling

After sediment vapor extraction port installation, each nested well assembly will be purged of atmospheric air introduced during drilling. Sulfur hexafluoride (SF6) will be entered as a tracer gas during the air drilling operations. After completion of the soil gas ports each monitoring implant will be purged. The purging procedure will be as follows: one initial soil gas sample will be collected and analyzed for SF6 at the start of the purging procedure to determine its initial concentration in the subsurface. A CO2/O2 meter will be used to monitor the soil gas stream during the purging of each soil gas monitoring implant. When CO2/O2 concentrations stabilize during the purging operation a second sample will be collected and analyzed for SF6 to determine if all air introduced during drilling has been purged from the subsurface.

After each extraction port has been sufficiently purged, a vapor moisture condensate sample will be collected for tritium analysis. Sediment vapor extraction port purging, sampling procedures, and material specifications are described below:

- Prior to vapor extraction port purging, nylon tubing will be attached to each nylon tubing riser of the nested well and routed to a 3 feet x 4 inch PVC manifold. The connection port of each riser at the PVC manifold will be fitted with a flow meter to regulate airflow from each vapor extraction port. A vacuum pump will be attached to the PVC manifold. The manifold assembly will be secured in a 5 feet x 8 feet trailer. Power for the vacuum pump will be provided by a 15 kilowatt (KW) diesel generator.
- To purge the vapor extraction ports of atmospheric air, soil vapor will be extracted at a flow rate of approximately 2,000 milliliters per minute (ml/min) from each extraction port. At this flowrate, each extraction port will extract approximately 3,000 liters per day (l/day) during the sampling process. Carbon dioxide and SF6 concentrations will be monitored at each flowmeter port for each extraction port using a GasTech GA-90 carbon dioxide detector. Purging will continue until carbon dioxide readings stabilize for all nested well intervals.
- After vapor extraction port purging has been completed, the nested well tubing assembly will be set up for sediment vapor sampling. A freeze trap sampling apparatus will be fitted to the stainless steel tubing run before it reaches the PVC vacuum manifold. The freeze trap will consist of an insulated lab pan filled with a mixture of dry ice and methanol. Within the pan, sample vials will be set up in a rack; a series of vials will be dedicated to a specific vapor extraction port. Two or three sample vials connected in series per vapor extraction port are recommended in order to condense the water out of the soil gas. Each nylon riser tubing will be fitted to a glass tubing vapor inlet port and outlet port at each sample vial using a Teflon™ sleeve. Teflon™ tubing will be used to connect the glass vapor





outlet port of final sample vial in series to the PVC vacuum manifold. The freeze trap assembly will be secured in a trailer with the manifold assembly.

- Sediment vapor will be drawn through the freeze trap at a vacuum flowrate of approximately 2,000 ml/min per vapor extraction port. The sample vials will collect condensation from sediment vapor for tritium analysis. A minimum sample volume of 20 ml of condensate per vapor extraction port will be required for tritium analysis. A target volume of minimum 50 ml condensate will be attempted. It is estimated that approximately 36 hours of constant 2,000 ml/min airflow per vapor extraction port will be required to collect a 20 to 50 ml condensate sample from each vapor extraction port of each nested well.

- Condensate method blanks for tritium analysis will be generated in the field concurrently during the sediment vapor sampling event. One blank will be generated for each sediment vapor well sampling event. The method blank sampling intake port will be placed in the headspace of a large container filled with tritium-free water. Tubing will run from this intake port to the same freeze trap sampling apparatus and PVC vacuum manifold used for the nested vapor extraction port sampling. Atmospheric air to replace that withdrawn from the tritium-free water container will be routed through at least two "upstream" freeze traps to remove atmospheric water vapor. The air entering the tritium-free water container will be injected below the water surface through a diffuser or porous stone to equilibrate with the tritium-free water. Method blank vapor will be drawn through the sampling apparatus at a vacuum flowrate of approximately 2,000 ml/min, and a 20 to 50 ml condensate sample volume will be collected.

The soil gas tubing will not be leak tested. The potential for leaks will be minimized because the tubing will be one continuous piece from the soil gas sampling port to the surface. However, leaks could occur when the discharge tubing is attached to the sampling port and at the interface between the discharge tubing and the sampling apparatus. If the tubing leaks where it is connected to the sampling port, it will not affect the data quality because it will still be sampling soil gas from the specific depth. The collection of field blanks for tritium analysis during the soil gas sampling events will allow us to determine if the interface between the discharge tubing and the sampling apparatus is leaking.

#### **4.5 BOREHOLE COMPLETION**

A 5 foot in length by 4 foot diameter concrete guard pipe with removable lid shall be installed to protect the wellheads and soil gas equipment from tampering. A six-inch thick concrete pad shall extend a minimum radius of 2 feet away from the guard pipe and shall be sloped to prevent the accumulation of surface water near the well. Locks will be provided which are keyed alike for each well.





## 4.6 HOLLOW STEM AUGER DRILLING

A total of 10 shallow (6 meter) core holes will be completed in fluvial/interfluvial environments south of the GB-06 site. Core sampling and handling will follow the applicable procedures outlined in Section 4.2.3, however the drilling rig will be a smaller, more manageable hollow stem auger (HSA) type. Five-foot cones will be collected for chlorine-36, chloride, bromide, and volumetric water content. Borings will be backfilled with native soils.

## 4.7 TRENCH CONSTRUCTION AND SAMPLING

Trenching will also be required in addition to the hollow stem auger drilling of the near surface sediments. The trenching will encompass both an interfluvial zone and ephemeral wash to investigate the differences in infiltration across these two contrasting environments. It may be necessary to construct two adjacent trenches to accomplish this objective. The trench is anticipated to be at least 8 meters in length (or two trenches 4 meters in length) by 2 meters in depth to accomplish this phase of the sampling.

### 4.7.1 Trench Installation

During a period anticipated to be free of precipitation, the trench will be constructed using surface excavation equipment and will be wide enough to allow trench wall sampling from the land surface to a depth of at least 2 meters. The trench will be constructed without any water used for dust suppression or other reasons. Temporary shading of the trench will be used to reduce evaporation from the exposed trench walls. No sources of tritium or chlorine-36 (other than ambient atmosphere) will be allowed near the trenching or sampling activities. A description of each trench will be completed by the field geologist. Records will be maintained by the field geologist regarding all aspects of trenching and sampling according to ASTM Methodologies D 4700-91 and D 1587-83 (Appendix V).

### 4.7.2 Trench Sampling

Immediately following trench construction, a gridded sampling network will be determined along the east wall of the trench. Soil samples will be collected directly beneath the wash bottom, at the wash/interfluvial interface and at the distal end of the trench beneath interfluvial sediments. Samples will be collected using a hand-held coring device at intervals of 15 cm from the land surface to the bottom of the trench. Samples will be collected from the bottom to top of the trench to avoid cross-contamination from the upper soil horizons. Sufficient sample volume is to be collected for chlorine-36 analysis and also for gravimetric water content. Samples will be immediately placed in air-tight containers, labeled and





transmitted to the laboratory. Photographs and detailed descriptive analysis of the east trench wall will be used to record and document the trenching operations. Additional sampling will be conducted if soil structural features such as root casts or fractures are observed. These additional samples will be collected vertically along any such features.

#### **4.8 SURVEYING**

All newly installed groundwater monitoring wells will be surveyed by a professional survey crew licensed in the State of California. Other non-permanent locations will be located horizontally using a Global Positioning System (GPS) instrument or a compass and tape measure. For each groundwater well, the elevation will be surveyed to the nearest 0.01 foot at the measuring point where uncapped well riser is marked for water level measurement. For all locations, ground surface elevations will be surveyed to the nearest 0.1 foot.

#### **4.9 EQUIPMENT CLEANING**

##### **4.9.1 Major Equipment**

Drilling and excavation equipment will be cleaned on wooden skids or a portable pad using a high-pressure hot water or steam cleaner. Water generated during clearing will be handled in accordance with Section 4.10.4.

##### **4.9.2 Sampling Equipment**

Sampling equipment such as solid sampling tubes and pumps will be cleaned in accordance with TtNUS SOP SA-7.1 (Appendix IV). Cleaning activities are anticipated to be conducted at a location approximately 0.5 to 1.0 mile from the site. Cleaning fluids will be collected, and discharged to the surface as per Section 4.10.4. All downhole equipment will be completely dry before reuse after cleaning.

#### **4.10 HANDLING AND DISPOSAL OF INVESTIGATION-DERIVED WASTE**

##### **4.10.1 Development Water**

All investigation-derived waste (IDW) generated from the development of monitoring wells during this investigation will be containerized in 55-gallon drums. At the completion of well development, development water will be released to the ground surface in the vicinity of the cleaning area as per Section 4.10.4.





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**4.10.2      Purge Water**

Purge water will be evaluated and handled in the same manner as development water.

**4.10.3      Drill Cuttings**

Drill cuttings will be collected in drums, labeled, and stored on-site for disposal by BLM.

**4.10.4      Cleaning Fluids**

Cleaning fluids (water) from high pressure washing of major equipment (i.e., drilling equipment) will be allowed to percolate into the ground at the cleaning location. Residual soil will be removed from the equipment, to the extent practical, prior to cleaning, and this soil will be handled as discussed in Section 4.10.3. The cleaning area will be located away from the borehole areas near the intersection of the main north/south access road and Interstate 40.





## **5.0 SAMPLE HANDLING PROCEDURES**

Sample handling includes the field-related considerations concerning the selection of sample containers, preservatives, allowable holding times, and analyses requested. Sample identification, packaging, and shipping are addressed in this section and BRE SOPs SA-6.1 and SA-6.2 (Appendix IV). Preservation requirements and procedures are summarized below. Section 6.0 discusses details concerning sample containers, volume requirements, preservatives, allowable holding times and analyses requested.

### **5.1 FIELD DOCUMENTATION**

For each borehole, a lithologic description of each sample and a complete log of each boring will be prepared by the field geologist in accordance with ASTM Methodology D 2488-90 and BRE SOP GH-1.5, contained in Appendices IV and V. At a minimum, the boring log will contain the following information:

- Boring or Well Identification
- Name of Drilling Contractor
- Sample Numbers and Types
- Sample Depths
- Standard Penetration Test Data
- Sample Recovery/Sample Interval
- Soil Density or Cohesiveness
- Soil Color
- Unified Soil Classification System (USCS) Material Description
- Location of Boring
- Drilling and well construction problems/deviations from this plan

In addition, depths of lithology changes, sample moisture observations, depth to water, drilling methods, and total depth of each borehole will be included on each log, as well as any other pertinent observations. An example of the boring log form is attached in Appendix IV.

Sample documentation consists of the completion of chain-of-custody (COC) reports and matrix-specific sample logsheets. COC reports are detailed in Section 5.4. Completion of sample logsheets are discussed along with the matrix-specific sampling procedures presented in Section 4.0.





In addition, various hardcover, bound, record books are maintained for each field activity. The master Site Logbook (BRE SOP SA-6.3, Appendix IV) serves as the overall record of field activities. Information included daily in the master Site Logbook includes weather conditions, identity and arrival and departure times of personnel, management issues, etc. Various field notebooks are also maintained. For example, each geologist supervising drilling operations at a specific sampling location will maintain a field notebook.

The FOL is responsible for the maintenance and security of all field records. Eventually, all field records (COCs, sample logsheets, logbooks, and notebooks), are docketed and incorporated in the project central file.

Field Task Modification Records (FTMRs) are specific forms initiated when a change to or deviation from procedures provided for in the project planning documents occurs. The procedure for requesting and recording procedural field changes follows:

- The FOL notifies the Project Manager (PM) of the need for the change.
- If necessary, the PM discusses the change with the pertinent individuals (e.g., BLM, BRE QA Manager). Verbal approval or denial of the proposed change is given at this time.
- The FOL then documents the change on an FTMR and forwards the form to the PM at the earliest convenient time (e.g., end of the workweek).
- The PM signs the form and distributes copies to the BLM, BRE QA Manager, FOL, and project file.
- A copy of the completed FTMR is attached to the field copy of the affected document.
- Any changes which affect project cost or scope of work must be approved in writing by the BLM contracting officer.

## **5.2 SAMPLE NOMENCLATURE**

Each sample collected at the Ward Valley site will be assigned a unique tracking number. The sample designation includes the sample or well location number, site number, and an indication of the sample matrix (e.g., soil, groundwater, or development water). The designations indicate--from left to right--matrix/sample





type, site number, sample location number, and sample depth, as needed. The sample locations identified in the Section 3.0 incorporate the sample matrix/type, site, and sample location numbers.

The standard sample type codes are summarized below:

Water Samples

GW - Groundwater Monitoring Well

DW - Development Water

Soil Samples

SB - Subsurface Soil

TP - Test Pit (Trench)

Other Codes

QC - Quality Control

SG - Soil Gas

AS - Air Sample

FB - Field Blank

SGC - Soil Gas Condensate

The QC sample code is usually used for drilling water and sand pack samples. Drilling water samples will be collected. Samples of the sand pack are not necessary, as analysis should be available from the manufacturer. Duplicates or split samples will be numbered sequentially using the 100 series in place of the sample location number. Field blanks will be labeled sequentially followed by the date (i.e., FB-01-013194).

### **5.3 PRESERVATION**

The existence of some chemical constituents in some environmental matrices is unstable. Therefore, these types of samples must be "stabilized" using preservatives and/or special handling procedures (such as maintaining the sample cores in a humidity controlled environment). These preservation techniques prevent (or forestall) degradation of the sample to ensure that the sample is representative of actual site conditions. Soil cores will be sealed in a low humidity, cool environment and sent to the primary laboratory in coolers with a single chemical ice pack. Samples do not require chilling to 4°C.





## 5.4 SAMPLE PACKAGING AND SHIPPING

Samples will be packaged and shipped in accordance with BRE SOP SA-6.2 contained in Appendix IV. In addition, to further assist the field crew, the following sample materials shipping checklist is provided:

- Packaging

1. Check for container integrity, especially the closure.
2. Check for sufficient absorbent material in package.
3. Check for sample tags and log sheets for each sample and for COC record.

The FOL will be responsible for completion of the following forms:

1. Sample Labels
2. COC Forms
3. Appropriate labels applied to shipping coolers
4. Custody Seals
5. Shipping Airbills

## 5.5 SAMPLE CUSTODY

Chain of custody forms are to be maintained and accompany all soil and water samples obtained during the drilling and sampling program. Sample shipment from the field to laboratories and archive facilities are to be done via the most practical method available to preserve sample integrity and chain of custody. The on-site FOL is to maintain a copy of the completed chain of custody forms, as does any responsible party during transport and storage before and at the appropriate laboratories. The BRE SOP SA-6.1 further details the COC procedures. An example of the COC record is included in Appendix IV.

## 5.6 QUALITY CONTROL SAMPLES

In addition to periodic calibration of field equipment and appropriate documentation, QC samples will be collected or generated during environmental sampling activities. QC samples include field blanks and duplicates samples. Each type of field QC sample is defined in Table 4-1.

Several laboratories will be required to perform the analytical work for this investigation. Sample splits for tritium analysis at two independent laboratories will be collected for at least 5% of the core samples





analyzed. Approximately 5% of the sediment vapor phase tritium samples will be collected for independent analysis by splitting the condensed vapor into 4 equal 50 ml parts, with 2 of the splits going to independent laboratories, one of the splits going to the primary laboratory and the fourth archived. Tritium is singled out for sample splits as it had been identified by the NAS for more detailed investigation. Splitting of core samples for tritium is recognized to be difficult and prolonged contact with the atmosphere during splitting will be avoided.

Sample splits from cores will be collected and handled in accordance with Section 4.2.4. The 5th brass sleeve will be sent to LLNL for splitting and distribution to independent laboratories for tritium analysis. The splits are to be sealed following core procedures outlined in Section 4.2. Five percent of the total number of samples will be used to identify possible systematic differences in analytical results.

## **5.7 SAMPLE ARCHIVE FACILITY**

Archived samples are to be stored in a secure, environmentally controlled BLM facility. Custody and distribution of sample blanks, sample splits of cores and all archived samples is the responsibility of the BLM project manager or a designated representative. Detailed records are required of the disposition of all archived samples.

### **5.7.1 Priorities for Archived Samples**

The highest priority for archived samples is to provide additional sample material to resolve any analytical or field-related questions identified during the reviews of the resulting databases. The second priority for archived samples is to provide material for interested stakeholders after archived samples are determined to be surplus by the BLM.

### **5.7.2 Disposition of Archived Samples**

The disposition of archived samples will be the responsibility of the BLM.





## 6.0 ANALYTICAL METHODS

The purpose of this Section is to address the analytical methods which will be used for this project and the internal laboratory QA samples associated with the methods. Copies of all analytical methods are included in Attachment VI of this work plan.

### 6.1 GEOTECHNICAL, ISOTOPE, AND CHLOROFLUOROCARBON ANALYTICAL METHODOLOGIES

Geotechnical, isotopic, and chlorofluorocarbon (CFC) analyses will be conducted by fixed-base laboratories who will have demonstrated previous experience in conducting the requested analyses.

The geotechnical analyses will be conducted in accordance with ASTM methodologies (soil moisture, ASTM D 2216; grain size, ASTM D 422 with hydrometer; and bulk density, ASTM D 2937) with the exception of the soil water bromide and chloride analyses which will be conducted in accordance with a U.S. EPA ion chromatography method (SW846 9056 or EPA 300.0). The water potential analysis will be conducted in accordance with a method referenced in either Soil Science Society of America or an American Society of Agronomy Journal (see Footnote 1, Table 6-1).

Table 6-1 provides a summary of the geotechnical analytical methods for the Ward Valley project. Samples will be submitted in brass sleeve tubes with plastic end caps. Each tube is one foot in length and 3 1/2 inches in diameter and will be shipped in sealed mylar or plastic bags.

The isotopic and chlorofluorocarbon analyses will be conducted in accordance with the procedures specified in Table 6-2. Sample container and sample volume requirements are also specified in Table 6-2. For tritium analyses, aqueous and soil gas condensate samples will be submitted in high density polyethylene (HDPE) bottles, either 275 ml or 50 ml capacity. Soil samples (or soil extract samples) will also be submitted in HDPE containers. Carbon-14, which will be determined for aqueous samples only, will be submitted in glass bottles (1 liter capacity). Soil gas samples, which will be analyzed for CFCs, will be submitted in stainless steel summa canisters. Each canister will contain approximately 6 liters of sample.





TABLE 6-1

## GEOTECHNICAL ANALYTICAL METHODS

Analysis	Method	Units	Sample Volume	Holding Time	Turnaround Time
Soil Moisture	ASTM D2216	% Moisture	(2)	None	30 days
Grain Size	ASTM D422 with hydrometer	% Gravel, sand, silt, clay	(2)	None	30 days
Bulk Density	ASTM 2937	Grams/cm <sup>(3)</sup>	(2)	None	30 days
Soil Water Bromide	SW-846 9056 or EPA 300.0	mg/g soil	(2)	28 days after extraction	30 days
Soil Water Chloride	SW-846 9056 or EPA 300.0	mg/g soil	(2)	28 days after extraction	30 days
Water Potential	(1)	Graph of matrix potential vs water content	(3)	None	60 to 90 days

(1) Water potential by one or more of the following methods.

a) Chilled Mirror Hygrometer

Gee, G.W., M.D. Campbell, G.S. Campbell and J.H. Campbell, 1992. Rapid Measurement of Low Soil Water Potentials Using a Water Activity Meter. Soil Science Society of America Journal, Vol. 56, pp. 1068-1070.

b) Thermocouple Psychrometer

Rawlins, S.L. and G.S. Campbell, 1986. Water Potential: Thermocouple Psychrometry, in Methods of Soil Analysis - Part 1, Edited by A. Klute, pp. 597-618. American Society of Agronomy, Madison, WI.

c) Filter Paper

Campbell, G.S. and G.W. Gee, 1986. Water Potential: Miscellaneous Methods, in Methods of Soil Analysis - Part 1, Edited by A. Klute, pp. 619-633. American Society of Agronomy, Madison, WI.

d) Tensiometric

Cassel, D.K. and A. Klute, 1986. Water Potential: Tensiometry, in Methods of Soil Analysis - Part 1, Edited by A. Klute, pp. 563-596. American Society of Agronomy, Madison, WI.

e) Gravimetric Water Content By Oven Drying

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ASTM Method D2216-92

(2) One foot soil column approximately 3-4 inches in diameter will be submitted for these 5 analyses.

(3) Four inch soil column approximately 3-4 inches in diameter.





TABLE 6-2

LABORATORY ISOTOPE AND CHLOROFLOROCARBON (CFC) ANALYTICAL METHODS<sup>(1)</sup>

Analytical Specifications			Containers/Volume Requirements		
Parameter	Method	PQL <sup>(2)</sup> /Units	Gas	Soil <sup>(4)</sup>	Aqueous
Tritium	Cryogenic Extraction (soil)	0.25 TU <sup>(5)</sup> *(soil/aqueous)	HDPE/275 ml	2 feet	HDPE 275 ml
	Electrolytic Enrichment and Liquid Scintillation Counting	0.1 TU (water from soil gas)			
	or Cryogenic Extraction (Soil) Helium In-growth	0.1 TU (soil/aqueous/water from soil gas)	HDPE/50 ml	2 feet	HDPE/50 ml
Carbon-14	Cryogenic Extraction Accelerator Mass Spectrometry	0.1% PMC <sup>(3)</sup>	NA	NA	glass/1 liter
Oxygen-18	Toluene Distillation Gas Ratio Mass Spectroscopy	$\pm 0.2$ Delta Notation as ppt	NA	1 foot	glass/100 mL
Deuterium	Toluene Distillation Gas Ratio Mass Spectroscopy	$\pm 1$ Delta Notation as ppt	NA	1 foot	glass/100 mL
CFC	EPA TO-14	0.2 Parts per billion	summa canister <sup>(6)</sup>	NA	NA

(1) The holding time for CFC analysis is 30 days. There are no holding time or preservation requirements for isotope analyses. Turnaround time for each parameter except tritium is 30 days. Tritium turnaround time for the counting method is 14-21 days for aqueous and soil gas (water condensate) samples and 21-28 days for soil samples; turnaround time for He in-growth is 6-12 months.

(2) PQL = Practical Quantitation Unit

(3) PMC = Percent Modern Carbon

(4) Minimum 3.5" diameter brass liners (or extract)

(5) TU = Tritium Unit

(6) Stainless steel container with approximately 6 liter capacity

NA = Not applicable

Note: For the tritium analysis, with 275 ml of water an effective error of  $\pm 0.1$  TU can be achieved using the electrolytic enrichment/liquid scintillation counting method. With 50 ml of water the error increases to  $\pm 0.2$  TU. With less than 50 ml of water, electrolytic enrichment is no longer practical and the helium in-growth method must be used. The effective error of helium in-growth is  $\pm 0.01$  TU.





---

## 6.2 INTERNAL LABORATORY QA

For the geotechnical analyses, pore water bromide and chloride laboratory QA samples will consist of initial and continuing calibration analyses, laboratory blank analyses, laboratory duplicate analyses and laboratory control sample results. The laboratory quality control for the water potential analysis will consist of replicate and check standards analyses.

For the remaining physical parameters (soil moisture, grain size, and bulk density) all internal laboratory QA will be conducted in conformance with the requirements of the respective analytical method.

The internal laboratory QA analyses for the isotope analyses consist of blanks, blind samples, and crosscheck samples.



1. The first part of the report is a general introduction to the project. It describes the purpose of the study, the objectives, and the scope of the work. It also provides a brief overview of the methodology used in the study.

2. The second part of the report is a detailed description of the methodology used in the study. It includes a description of the data collection methods, the data analysis methods, and the statistical tests used.

3. The third part of the report is a presentation of the results of the study. It includes a description of the data, a presentation of the statistical results, and a discussion of the findings.

4. The fourth part of the report is a conclusion and a discussion of the implications of the study. It includes a summary of the findings, a discussion of the limitations of the study, and a discussion of the implications of the findings for future research.





## **7.0 DATA VALIDATION AND REPORTING**

### **7.1 LABORATORY DATA VALIDATION**

One hundred percent of the laboratory data will be validated. Validation of analytical data will be completed by TtNUS chemists and final review and approval of validation deliverables will be completed by the TtNUS Data Validation Coordinator.

All isotope laboratory data will be subjected to validation in accordance with the method-specific QA criteria and will be evaluated based on background, laboratory standard, and raw sample activities. Data completeness, sample quantitation, and holding times will also be evaluated.

Pore water bromide and chloride laboratory data will be validated in accordance with the method-specific QA criteria, and with the most current EPA Statement of Work for inorganic analysis (USEPA, 1994). Data will be requested from the laboratory in EPA Contract Laboratory Program - like format and these data will be evaluated based on completeness, holding time compliance, equipment calibration, laboratory blank results, surrogate spike recoveries, constituent identification, and constituent quantitation.

Data validation will be completed to ensure that the data are of evidentiary quality.

### **7.2 REPORTING**

The report will present a summary of field activities, all reduced data in tables for samples collected with a summary of any QA/QC problems with the TtNUS laboratories and the associated corrective actions taken. In addition, TtNUS will provide in Appendices all boring logs, sample log forms, and COCs.





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1. The first part of the report deals with the general situation of the country and the position of the various groups of the population.

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3. The third part of the report deals with the social situation of the country and the position of the various groups of the population.

4. The fourth part of the report deals with the cultural situation of the country and the position of the various groups of the population.

5. The fifth part of the report deals with the political situation of the country and the position of the various groups of the population.

6. The sixth part of the report deals with the international situation of the country and the position of the various groups of the population.

7. The seventh part of the report deals with the future of the country and the position of the various groups of the population.

8. The eighth part of the report deals with the conclusion of the report and the position of the various groups of the population.

9. The ninth part of the report deals with the appendix of the report and the position of the various groups of the population.

10. The tenth part of the report deals with the bibliography of the report and the position of the various groups of the population.

11. The eleventh part of the report deals with the index of the report and the position of the various groups of the population.

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24





**APPENDIX I**  
**SITE SECURITY PLAN**





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## **1.0 INTRODUCTION**

The Ward Valley site consists of approximately 1000 acres of Federal land managed by the Department of Interior's Bureau of Land Management (BLM) located 20 miles west of Needles, California. The site evaluation project to be conducted by the Department of Interior is based on sampling protocols developed by the BLM. Most of the activity planned for the project includes drilling and sampling which will take place within existing disturbed areas over the 1000 acre site. An active security program is necessary at the site to help insure integrity of the sampling effort and to protect equipment and materials from vandalism.

Security will be provided by Guard Force Services, Inc., an experienced site security company, under subcontract to Tetra Tech NUS and CCJM, Inc. Guard Force Services is based in Bullhead City, Arizona.

The main secured area will be Area 06, the largest existing disturbed area at the site. The office trailer, sample preparation trailer, equipment laydown area, and generators will be located here within a 100 foot square chain link fence with a locking gate (Figure A1-1). The other secured areas will be the drill sites which will be under 24 hour observation from site workers and the security guard. The drill sites will be unfenced, but the drill hole will be covered and sealed each night and over weekends. Sample cores, soil gas condensate samples, and water samples not shipped each day will be locked overnight in the sample preparation trailer within the fenced and guarded work compound.

## **2.0 FENCING AND TEMPORARY STRUCTURES**

### **2.1 FENCING**

The perimeter of the work compound will be fenced with a temporary eight foot high chain-link fence to prevent unauthorized entry to the trailers and laydown area. The TtNUS Project Manager and key personnel will maintain control of access to the compound through a single gate secured by a chain and padlock when personnel are not present. The following are the specifications for the fencing to be installed at the Ward Valley site in Area 06.

1. Fencing shall consist of a woven galvanized wire type (i.e. 'chain link'), and shall be installed to a final height of 8 feet above grade. Top and bottom rails shall be provided for stability.

The first part of the chapter is devoted to a discussion of the various methods of determining the rate of a chemical reaction. The second part of the chapter is devoted to a discussion of the various factors which influence the rate of a chemical reaction. The third part of the chapter is devoted to a discussion of the various theories of chemical reaction rates.

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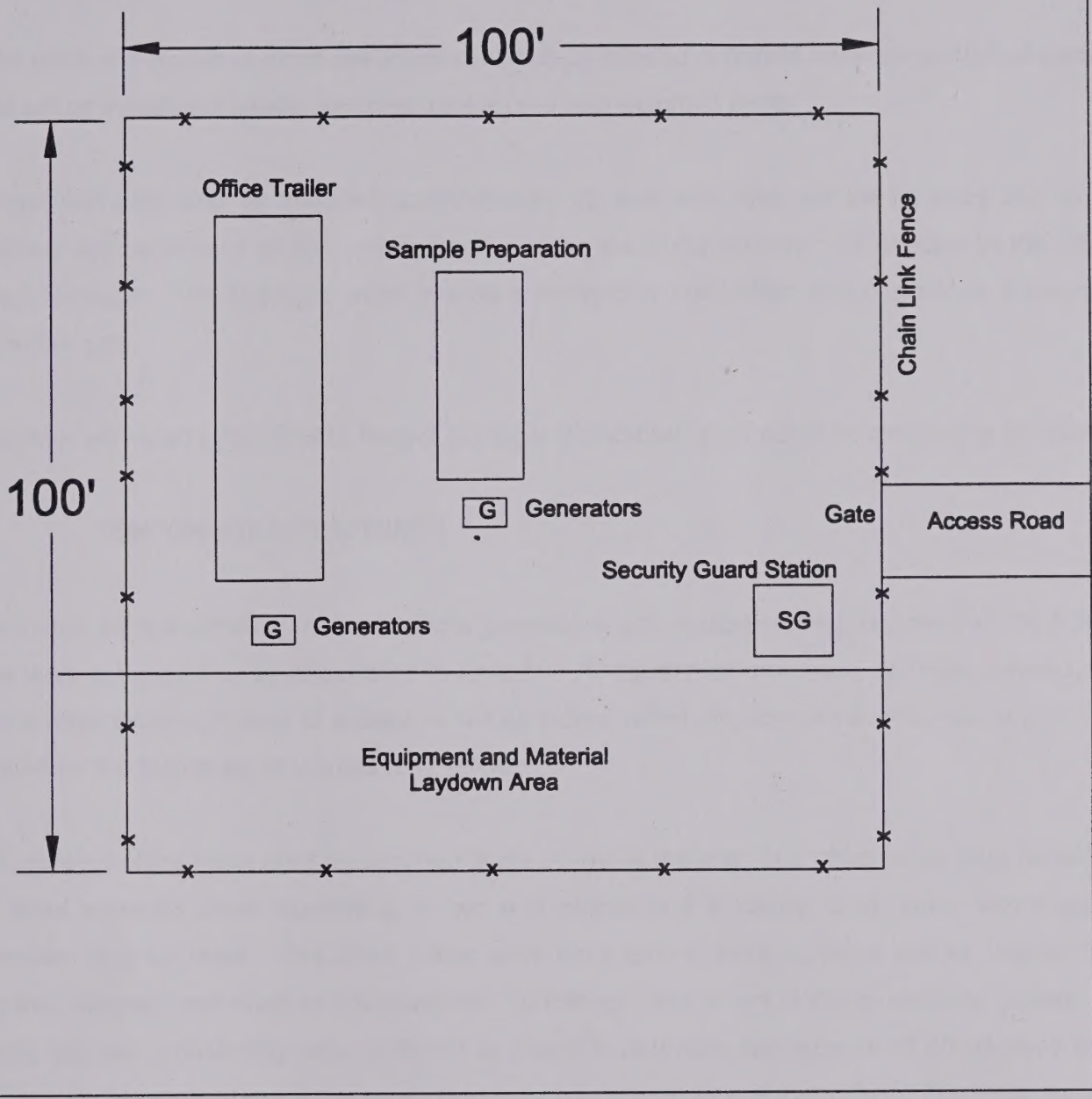
### EXERCISES


#### 10.1

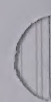
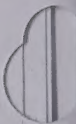
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The first part of the chapter is devoted to a discussion of the various methods of determining the rate of a chemical reaction.





DRAWN BY WLR		DATE DEC 97	 Tetra Tech NUS, Inc.	CONTRACT NO. A376-BLM-01		TASK ORDER: 054	
CHECKED BY DB		DATE DEC 97		APPROVED BY _____ DATE _____			
SCALE  AS SHOWN			General Site Layout - Area 06 Ward Valley, California	APPROVED BY _____ DATE _____			
				Figure A1-1			REV. 0



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- 
2. Fencing shall be installed around the perimeter of the designated work area. Although the final configuration has not yet been established, an area approximately 100 feet by 100 feet (approximately 400 linear feet) is estimated to be necessary.
  3. Fence posts will consist of minimum 3 inch diameter galvanized materials installed on 10 foot centers. Posts will be installed at grade, and shall be secured with weighted posts.
  4. A single leaf gate shall be installed, approximately 15 feet wide, that will permit entry and exit of personnel and vehicles at an appropriate location along the fence perimeter, as directed by the TtNUS Project Manager. The contractor shall provide a heavy-duty steel chain and padlock as a means to secure the gate.
  5. Contractor will report to the TtNUS Project Manager to establish a schedule for conducting the work.

## **2.2 TEMPORARY STRUCTURES**

An office trailer, sample handling trailer, portable generators, and equipment laydown area will be located within the work compound to be established in Area 06. All equipment, materials, drill rigs, vehicles, and other items requiring a high level of protection will be stored within the compound when not in use. The specification for the temporary structures is as follows:

1. A 40 foot long office trailer shall be provided and installed at the site. The office trailer shall be divided into three separate areas consisting of two end offices and a central work area, with separate entrances for each area. The office trailer shall have built-in work surfaces (desks, tables, filing cabinets, shelves), and shall be equipped with 10 folding metal chairs, lighting, electrical outlets, and heating and air conditioning units sufficient to maintain an inside temperature of 60 degrees F. A minimum of 4 mercury vapor lights shall be installed on the exterior of the trailer to illuminate the yard area at night. The trailer shall be equipped with a metal skirt to prevent access to the underside of the trailer by animals. The trailer shall be equipped with stairs, as necessary, to afford entry from ground level, and door locks. Three sets of keys shall be provided to the TtNUS Project Manager.
2. A portable gasoline or diesel generator and a backup unit shall be supplied and installed to provide electric service to the trailer and for support functions. Generators shall be equipped with mufflers to reduce noise from their operation, and sized to provide sufficient power to all electrically operated equipment.

1. The first part of the report deals with the general situation of the country and the results of the survey. It is divided into two main sections: the first section deals with the general situation of the country and the second section deals with the results of the survey.

2. The second part of the report deals with the results of the survey. It is divided into two main sections: the first section deals with the results of the survey and the second section deals with the results of the survey.

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10. The tenth part of the report deals with the results of the survey. It is divided into two main sections: the first section deals with the results of the survey and the second section deals with the results of the survey.



- 
- 1 3. A single portable sanitary unit shall be supplied and installed. Contractor shall be responsible for  
2 making arrangements to have the unit cleaned and serviced on a weekly basis during the time that  
3 TtNUS personnel are at the site.  
4
  - 5 4. At the conclusion of the project, the contractor shall dismantle and remove the office trailer and all  
6 installed components from the site, including any wastes generated from the dismantling operation.  
7
  - 8 5. Contractor will report to the TtNUS Project Manager to establish a schedule for completing the work.  
9

### 10 **3.0 SECURITY GUARDS/COMMUNICATIONS**

11  
12 Uniformed security guards will be present 24 hours a day to patrol the work compound and investigation  
13 areas. Guards will not be armed, but will have the authority to stop and remove unauthorized persons and  
14 to patrol all areas of the site. Security guards will be equipped with a vehicle and two-way radios or  
15 cellular phones to report disturbances or unusual occurrences to the appropriate law enforcement  
16 authorities and to the TtNUS Project Manager. The TtNUS field operation leader will also have a cellular  
17 phone for communications. The sample trailer and drill rig will communicate with two-way radios. The  
18 specification for security services is as follows:  
19

- 20 1. A licensed and trained security guard shall be provided on a 24 hour per day, 7 days per week  
21 basis. Security personnel will patrol the work area and other areas of the site as directed by the  
22 TtNUS Project Manager.  
23
- 24 2. Security guards will be required to report to the TtNUS Project Manager during working hours and will  
25 file shift reports documenting their observation while on patrol. Shifts will be coordinated by the  
26 TtNUS Project Manager to avoid interruptions of the sampling work shift (8 AM to 5 PM).  
27
- 28 3. Security guards shall be uniformed, but will not be required to have firearms in their possession.  
29
- 30 4. Communication equipment in good working order shall be provided at all times (2 way radios or cell  
31 phones) while on duty. Security guards will be expected to report all unusual activities, evidence of  
32 vandalism, or threats by persons not working at the site, and to call appropriate law enforcement  
33 agencies as needed, if dangers to the health and well-being of personnel working at the site are  
34 presented.  
35

1. The first part of the document is a letter from the President of the United States to the Congress, dated January 3, 1862. It is a very important document, as it contains the President's views on the state of the Union and the progress of the war.

2. The second part of the document is a report from the Secretary of the War Department, dated January 10, 1862. It contains a detailed account of the military operations of the Army during the year 1861.

3. The third part of the document is a report from the Secretary of the Navy Department, dated January 10, 1862. It contains a detailed account of the naval operations of the Navy during the year 1861.

4. The fourth part of the document is a report from the Secretary of the Department of the Interior, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.

5. The fifth part of the document is a report from the Secretary of the Department of the Treasury, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.

6. The sixth part of the document is a report from the Secretary of the Department of the State, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.

7. The seventh part of the document is a report from the Secretary of the Department of the War, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.

8. The eighth part of the document is a report from the Secretary of the Department of the Navy, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.

9. The ninth part of the document is a report from the Secretary of the Department of the Interior, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.

10. The tenth part of the document is a report from the Secretary of the Department of the Treasury, dated January 10, 1862. It contains a detailed account of the operations of the Department during the year 1861.



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5. Access to the site is available by automobile. The security subcontractor shall provide a company-owned (marked or unmarked) vehicle for security personnel while on duty.

**4.0 SITE CONTROL PROCEDURES**

The site security guard will maintain a sign in/sign out log for all site personnel. The daily logs will be turned over to the TtNUS Project Manager and kept in the on-site file for the duration of the field effort. The logs will be permanently filed in the project file maintained by TtNUS. No unauthorized visitors will be allowed within the work compound or within the work area of the drilling rigs or sampling equipment.

A list of authorized personnel will be provided to TtNUS by BLM prior to the initiation of field work. BLM will also provide a telephone number to be called during the work day to obtain verbal authorization for access to the site.

1. The first part of the report is a general introduction to the subject of the study. It discusses the importance of the study and the objectives of the research.

## 2. The second part of the report is a detailed description of the methodology used in the study.

The methodology section describes the data collection methods, the sample size, and the statistical analysis techniques used. It also discusses the limitations of the study and the potential sources of error.

The results section presents the findings of the study, including the mean values, standard deviations, and the results of the statistical tests. It also discusses the implications of the findings for the field of study.

The conclusion section summarizes the main findings of the study and provides recommendations for future research.



**APPENDIX II**  
**HEALTH AND SAFETY PLAN**





**FINAL  
HEALTH AND SAFETY PLAN  
FOR  
WARD VALLEY SITE EVALUATION  
WARD VALLEY, CALIFORNIA**

**JANUARY 1998**

**Submitted by:  
Tetra Tech NUS  
Suite 400, 910 Copper Road  
Gaithersburg, Maryland 20878**

**SUCONTRACT NUMBER A376-BLM3-00**

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## 1.0 INTRODUCTION

This Health and Safety Plan (HASP) has been written to encompass site activities that are to be conducted at Ward Valley in Ward Valley, California as part of Subcontract A376-BLM3-00. This Site Evaluation is part of an overall effort considering a request by the State of California to transfer 1,000 acres of federally owned land for siting a proposed Low-Level Radioactive Waste disposal facility. In addition to this HASP, a copy of the Tetra Tech NUS (TtNUS) Health and Safety Guidance Manual must be present at the site during the performance of site activities. This guidance manual provides detailed information pertaining to the HASP as well as TtNUS standard operating procedures (SOPs). Both documents must be present at the site in accordance to Occupational Safety and Health Administration (OSHA) standard 29 CFR 1910.120.

This HASP has been developed using the latest available information regarding known or suspected chemical contaminants and potential physical hazards associated with the proposed work and site. The HASP will be modified if new information becomes available. All changes to the HASP will be made with the approval of the TtNUS Health and Safety Manager (HSM) and the Project Manager. The Project Manager (PM) will notify affected personnel of all changes. A Site Safety Follow-up Report will document all changes to the HASP.

The elements of this HASP are modeled after the requirements established by OSHA 29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response" (HAZWOPER), and sections of 29 CFR 1926, "Safety and Health Regulations for Construction." However, this is not a hazardous site and all hazwoper requirements do not apply. However, this is not a hazardous waste site and all HAZWOPER requirements do not apply. The information contained in this plan, as well as policies on conducting onsite operations, has been obtained from the TtNUS Health and Safety Program.

## 1.1 KEY PROJECT PERSONNEL AND ORGANIZATION

This section defines responsibility for site health and safety for TtNUS and subcontractor employees. Personnel assigned to these positions are responsible for all onsite health and safety. These people are primary points of contact for questions regarding any procedures or control measures.

- The TtNUS PM is responsible for the overall direction and implementation of health and safety for this project.

The first part of the paper is devoted to a discussion of the various methods which have been proposed for the determination of the rate of reaction between a solid and a liquid. It is found that the most reliable method is that of measuring the change in weight of the solid as the reaction proceeds. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid. In cases where the reaction is too rapid, the method of measuring the change in volume of the solid may be used. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid. In cases where the reaction is too rapid, the method of measuring the change in volume of the solid may be used. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid.

The second part of the paper is devoted to a discussion of the various methods which have been proposed for the determination of the rate of reaction between a solid and a liquid. It is found that the most reliable method is that of measuring the change in weight of the solid as the reaction proceeds. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid. In cases where the reaction is too rapid, the method of measuring the change in volume of the solid may be used. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid.

The third part of the paper is devoted to a discussion of the various methods which have been proposed for the determination of the rate of reaction between a solid and a liquid. It is found that the most reliable method is that of measuring the change in weight of the solid as the reaction proceeds. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid. In cases where the reaction is too rapid, the method of measuring the change in volume of the solid may be used. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid.

The fourth part of the paper is devoted to a discussion of the various methods which have been proposed for the determination of the rate of reaction between a solid and a liquid. It is found that the most reliable method is that of measuring the change in weight of the solid as the reaction proceeds. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid. In cases where the reaction is too rapid, the method of measuring the change in volume of the solid may be used. This method is applicable to all cases in which the solid is insoluble in the liquid and the reaction is not too rapid.

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1 • The TtNUS Field Operations Leader (FOL) is responsible for implementation of this HASP and will  
2 also serve as the Site Safety Officer (SSO). The TtNUS field geologist may also serve as SSO. The  
3 FOL manages field activities, executes the work plan, and enforces safety procedures.

4  
5 • The SSO duties may include the following:

- 6
- 7 - Coordinates all health and safety activities with the BLM and subcontractors.
  - 8 - Selects, inspects, implements, and maintains personal protective equipment.
  - 9 - Establishes work zones and control points.
  - 10 - Directs and assists in the development of decontamination areas and procedures.
  - 11 - Implements air-monitoring program for onsite activities, if needed.
  - 12 - Verifies training and medical status of onsite personnel status in relation to site activities.
  - 13 - Implements hazard communication, respiratory protection, and other health and safety
  - 14 programs.
  - 15 - Coordinates emergency services.
  - 16 - Provides site-specific training for all onsite personnel.
- 17

18 • In the event of an imminent danger or life-threatening situation, the FOL/SSO have the authority to  
19 stop site operations. All personnel must immediately notify the FOL when conditions may warrant  
20 termination of operations. Should the FOL/SSO be unavailable, any employee or project-related  
21 personnel has the authority to terminate operations for health and safety reasons.

22

23 • Compliance with these requirements is monitored by the SSO and coordinated through the TtNUS  
24 Health and Safety Manager.

The first part of the paper is devoted to a discussion of the general principles of the theory of the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics, which are based on the principles of wave mechanics.

The second part of the paper is devoted to a discussion of the application of the theory of the structure of the atom to the study of the properties of matter. It is shown that the theory of the structure of the atom can be used to explain the properties of matter, such as the properties of the elements of the periodic table.

The third part of the paper is devoted to a discussion of the application of the theory of the structure of the atom to the study of the properties of the elements of the periodic table. It is shown that the theory of the structure of the atom can be used to explain the properties of the elements of the periodic table, such as the properties of the elements of the first and second groups.

The fourth part of the paper is devoted to a discussion of the application of the theory of the structure of the atom to the study of the properties of the elements of the periodic table. It is shown that the theory of the structure of the atom can be used to explain the properties of the elements of the periodic table, such as the properties of the elements of the third and fourth groups.



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**1.2 SITE INFORMATION AND PERSONNEL ASSIGNMENTS**

<b>Site Name:</b>	<u>Ward Valley</u>	<b>Address:</b>	<u>Needles, California</u>
<b>Project Manager</b>	<u>Karl Ford (BLM)</u>	<b>Phone Number:</b>	<u>(303) 236-3508</u>
<b>Site Contact:</b>	<u>Brent Lewis (BLM)</u>	<b>Phone Number:</b>	<u>(303) 236-3508</u>
<b>Site Contact:</b>	<u></u>	<b>Phone Number:</b>	<u></u>

**Purpose of Visit:** This activity will be divided into a multi-task operation performed sequentially through the execution of the elements as defined in the scope of work.

**Proposed Dates of Work:** January 98 - April 98

**Project Team:**

<b>TtNUS Personnel:</b>	<b>Discipline/Tasks Assigned:</b>
<u>Dennis Beissel</u>	<u>Project Manager</u>
<u>Frank Morris / Jeff Johnston</u>	<u>Field Operations Leader (FOL)</u>
<u>Matthew M. Soltis, CIH, CSP</u>	<u>Health and Safety Manager (HSM)</u>
<u>Frank Morris</u>	<u>Site Safety Officer (SSO)</u>
<u>David Schnackenberg / Stephanie Perez /</u>	
<u>Brian Wolfe</u>	<u>Geologists / Field Personnel</u>

<b>Non-TtNUS Personnel</b>	<b>Affiliation/Discipline/Tasks Assigned</b>
<u></u>	<u></u>
<u></u>	<u></u>

<b>Drilling Company Personnel</b>	<b>Discipline/Tasks Assigned</b>
<u></u>	<u>Driller/Sampler</u>
<u></u>	<u>Driller/Sampler</u>
<u></u>	<u>Driller/Sampler</u>

THE HISTORY OF THE

CHAPTER I

SECTION I

SECTION II

SECTION III

SECTION IV

SECTION V

SECTION VI

SECTION VII

SECTION VIII

SECTION IX

SECTION X

SECTION XI

SECTION XII

SECTION XIII

SECTION XIV

SECTION XV

SECTION XVI

SECTION XVII

SECTION XVIII

SECTION XIX



Drilling Company Personnel (continued)

### Discipline/Tasks Assigned

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Driller/Sampler

Driller/Sampler

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**Prepared by:** David J. Schnackenberg

**Modified by:** Dennis Beissel

Reviewed and Approved by:

Dennis Beissel  
Project Manager

Matthew M. Soltis, CIH, CSP  
Health & Safety Manager





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1     **2.0                   EMERGENCY ACTION PLAN**

2

3     **2.1                   INTRODUCTION**

4

5     This section has been developed as part of a planning effort to direct and guide field personnel in the

6     event of an emergency. When onsite emergencies that cannot be handled by onsite personnel occur, site

7     personnel will be evacuated to a safe place of refuge, and the appropriate emergency response agencies

8     will be notified. Because a majority of potential emergency situations will require assistance from outside

9     emergency responders, TtNUS and subcontractor personnel will not provide emergency response support

10    for significant emergency events beyond their capabilities. The emergency response agencies listed in

11    this plan are capable of providing effective response and will are designated as the primary responders.

12    These agencies are located within a reasonable distance from the Ward Valley area of operations and are

13    capable of providing adequate emergency response time. This emergency action plan models the OSHA

14    Standard 29 CFR 1910.38(a), as allowed in OSHA 29 CFR 1910.120(I)(1)(ii).

15

16    TtNUS will, through necessary services, include incidental response measures for incidents such as:

- 17
- 18    • Incipient fire-fighting support and prevention
  - 19    • Incipient spill control and containment measures and prevention
  - 20    • Removal of personnel from emergency situations
  - 21    • Provision of initial medical support for injury/illnesses requiring only first-aid-level support
  - 22    • Provision of site control and security measures as necessary
- 23

24    **2.2                   PRE-EMERGENCY PLANNING**

25

26    Through the initial hazard/risk assessment effort, injury or illnesses resulting from exposure to chemical or

27    physical hazards or fire are the most probable emergencies that could be encountered during site

28    activities. To minimize and eliminate these potential emergency situations, pre-emergency planning

29    activities associated with this project include the following. The SSO and/or the FOL are responsible for:

- 30
- 31    • Coordinating response actions with Emergency Services personnel to ensure that TtNUS emergency
  - 32      action activities are compatible with existing facility emergency response procedures.
  - 33
  - 34    • Establishing and maintaining information at the project staging area (support zone) for easy access in
  - 35      the event of an emergency. This information will include the following:
- 36

The first of these is the fact that the University of Chicago is a private institution. This means that it is not subject to the same regulations as public universities. The second is the fact that the University of Chicago is a research institution. This means that it is not subject to the same regulations as teaching institutions. The third is the fact that the University of Chicago is a non-profit institution. This means that it is not subject to the same regulations as for-profit institutions.

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- 
- Chemical Inventory (for substances used on site), with Material Safety Data Sheets.
  - Onsite personnel medical records (medical data sheets).
  - A logbook identifying personnel on site each day.
- Identifying a chain of command for emergency action.
  - Educating site workers to the hazards and control measures associated with planned activities at the site, and providing early recognition and prevention, where possible.
  - Drilling and practicing incidental response measures periodically.

It will be the responsibility of the TtNUS FOL to ensure that this information is available and present at the site.

## **2.3 EMERGENCY RECOGNITION AND PREVENTION**

### **2.3.1 Recognition**

Foreseeable emergency situations that may be encountered during site activities will generally be recognizable by visual observation. Visual observation will be the principal method of identifying physical hazards that may be associated with the proposed scope of work. Visual observation will also play a role in detecting some chemical overexposures. A clear knowledge of what signs and symptoms which may be evident in the event of overexposure to contaminants of concern may alert personnel of the potential hazard concerning themselves or in their fellow workers. These potential hazards, the activities with which they have been associated, and the recommended control methods are discussed in detail in Sections 5.0 and 6.0 of this document. Additionally, early recognition will be supported by periodic site surveys to eliminate any situation predisposed to an emergency. The FOL and the SSO will constitute the site evaluation committee responsible for these periodic surveys. Site surveys will be conducted at least once a week during the initiation of this effort.

The above actions will provide early recognition for potential emergency situations. TtNUS will provide incipient stage support. Should an incident take place, TtNUS will take defensive and offensive measures to control these situations. However, if the FOL/SSO determine that an incident has progressed to a serious emergency situation, TtNUS will withdraw, and notify the appropriate response agencies.





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### **2.3.2            Prevention**

TtNUS and subcontractor personnel will minimize the potential for emergencies by ensuring compliance with the HASP and the Health and Safety Guidance Manual.

### **2.4                    SAFE DISTANCES AND PLACES OF REFUGE**

In the event that the site must be evacuated, all personnel will immediately stop activities and report to the support zone area. The support zone, telephone communication points, and safe places of refuge will be determined prior to the commencement of site activities and will be conveyed to personnel as part of the daily safety meeting conducted each morning. Upon reporting to the refuge location, personnel will remain there until directed otherwise by the TtNUS FOL. The FOL/SSO will take a head count at this location to confirm the location of all site personnel. The site logbook will be used to take the head count.

### **2.5                    EVACUATION ROUTES AND PROCEDURES**

Once an evacuation is initiated, personnel will proceed immediately to the designated place of refuge in the support zone, unless doing so would further jeopardize the welfare of workers. In such an event, personnel will proceed to a designated alternate location (to be identified) and remain there until further notification from the FOL. The use of these locations as assembly points provides communication and a direction point for emergency services, should they be needed.

Evacuation procedures will be discussed prior to the initiation of any work at the site. This shall include identifying primary and secondary evacuation routes and assembly points. Evacuation routes from the site are dependent upon the location at which work is being performed and the circumstances under which an evacuation is required. Additionally, site location and meteorological conditions (i.e., wind speed and direction) will influence the designation of evacuation routes. As a result, assembly points at Ward Valley were selected, and in the event of an emergency, field personnel will proceed to these points by the most direct route possible without further endangering themselves.

### **2.6                    DECONTAMINATION PROCEDURES/EMERGENCY MEDICAL TREATMENT**

During a site evacuation, decontamination procedures will be performed only if doing so does not further jeopardize the welfare of site workers. Decontamination will not be performed if the action that initiates an evacuation would further endanger the lives of workers. However, it is unlikely that an evacuation would





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occur at this site which would require workers to evacuate the site without first performing decontamination procedures.

## **2.7 EMERGENCY ALERTING AND ACTION/RESPONSE PROCEDURES**

Since TtNUS personnel will not always be working in proximity to each other, hand signals, voice commands, air horns, and two-way radios will comprise the mechanisms to alert site personnel of an emergency.

If an accident occurs, site personnel will initiate the following procedures:

- Initiate incident alerting procedures (if needed) verbally, by air horn, or using two-way radios.
- Describe to the FOL (who will serve as the Incident Coordinator) what has occurred and as many details as possible. Once all personnel are evacuated, incipient response procedures will be enacted to control the situation.

In the event that site personnel cannot control the incident through offensive and/or defensive measures, the FOL/SSO will enact the emergency notification procedure to secure additional outside assistance in the following manner:

- Call 911 and report the emergency.
- Give the emergency operator the location of the emergency and a brief description of what has occurred.
- Stay on the phone follow the instructions given by the operator.
- The appropriate agency will be notified and dispatched.

If an accident occurs at Ward Valley outside of our designated operating areas impacting field personnel, the following procedures are to be initiated:

- Initiate an evacuation (if needed) by voice commands, hand signals, air horns, or two-way radio.
- Proceed to the assembly points as directed by TtNUS.





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## 2.9 EMERGENCY CONTACTS

## 2.10 EMERGENCY ROUTE TO HOSPITAL

Needles-Desert Communities Hospital  
1401 Bailey Ave.  
Needles, California  
(760) 326-4531

- Exit site to Highway 40 East.
- Proceed approximately 15 miles east to the J Street exit in Needles and turn right (south).
- Proceed approximately 2-3 blocks to Bailey Avenue and turn left.
- Go past City Hall and follow signs to entrance of Needles-Desert Communities Hospital.





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**TABLE 2-1**  
**EMERGENCY REFERENCE**  
**WARD VALLEY, CALIFORNIA**

AGENCY	TELEPHONE
EMERGENCY ASSISTANCE	
SECURTIY	911
MEDICAL	911
FIRE	911
HAZARDOUS MATERIALS	911
Needles-Desert Communities Hospital, California	(760) 326-4531
TtNUS, Gaithersburg Office	(301) 258-6000
Health and Safety Manager Matthew M. Soltis, CIH, CSP	(412) 921-8912
Project Health and Safety Officer Frank Morris	(301) 258-6030
Project Manager Dennis Beissel	(301) 258-8736
Field Operations Leader Frank Morris	(301) 258-6030

7  
8  
9

# THE STATE OF NEW YORK DEPARTMENT OF AGRICULTURE

NAME	ADDRESS
J. H. BROWN 123 Main St. New York City	J. H. BROWN 123 Main St. New York City
W. J. SMITH 456 Elm St. Albany	W. J. SMITH 456 Elm St. Albany
C. D. JONES 789 Oak St. Syracuse	C. D. JONES 789 Oak St. Syracuse
M. L. GARCIA 101 Pine St. Buffalo	M. L. GARCIA 101 Pine St. Buffalo



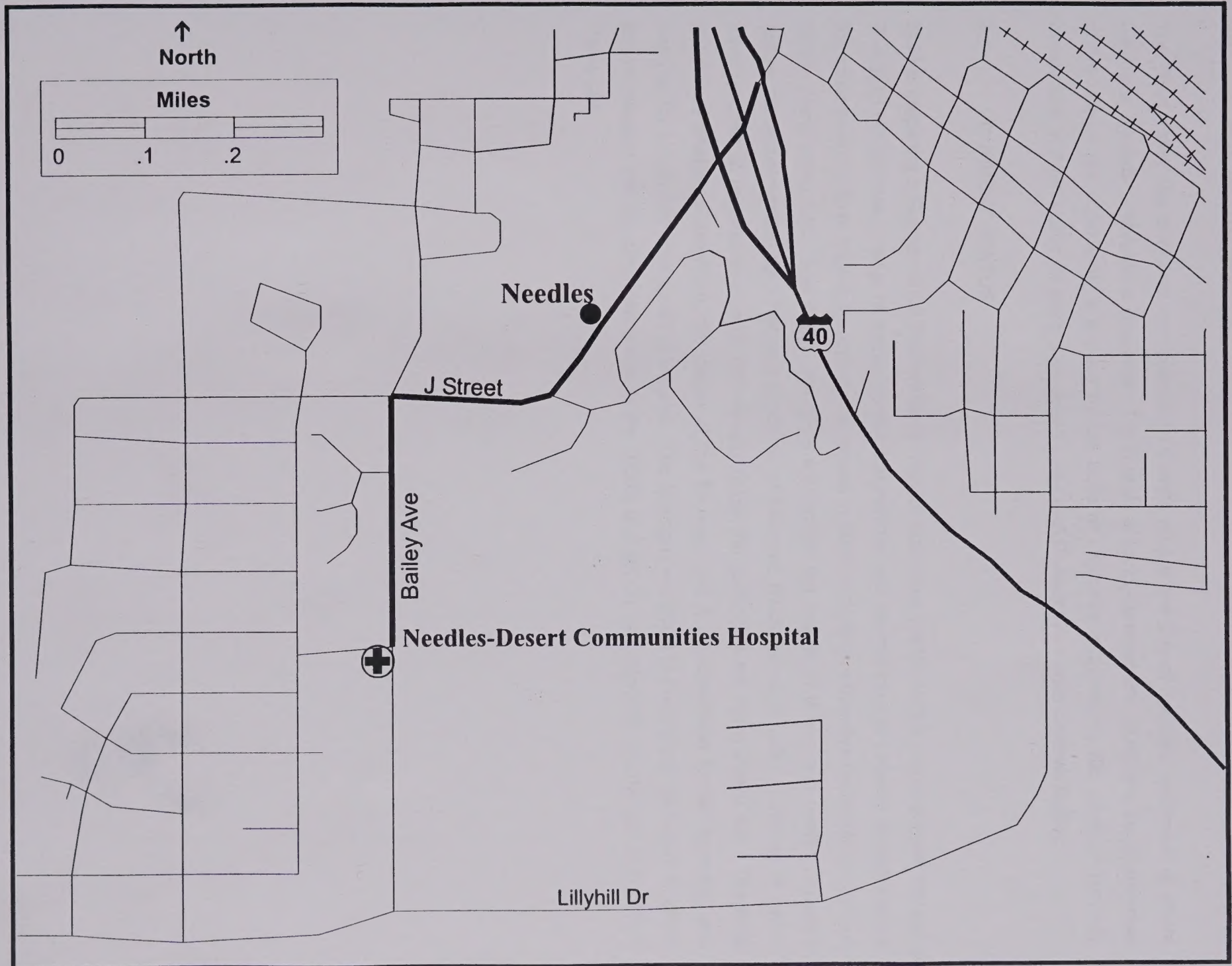


Figure 2-1 Hospital Route Map





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1    **3.0            SITE BACKGROUND**

2

3    The Ward Valley site is located approximately 15 miles west of the City of Needles, southwest of where  
4    California, Nevada, and Arizona converge. The Bureau of Land Management (BLM) and the Department  
5    of the Interior are considering a request by the State of California to transfer 1,000 acres of federally  
6    owned land at Ward Valley for siting a proposed Low-Level Radioactive Waste disposal facility.

7

8    **3.1            CURRENT STATUS**

9

10   BLM is preparing a Supplemental Environmental Impact Statement (SEIS) on the proposed land transfer.  
11   The SEIS will address a range of issues on which significant new information has become available since  
12   the initial environmental impact statement was issued in 1991, including radioactive movement in the soil  
13   at the Ward Valley site. Specifically, the SEIS will include the results of tritium and related materials  
14   testing, as recommended by a National Academy of Sciences (NAS) panel in 1995. Findings of tritium  
15   were reported at considerable depth (30 meters) below the surface at the Ward Valley site. The NAS  
16   panel was unable to determine the cause of the findings, and it recommended further sampling and  
17   analysis for tritium and chlorine-36 at the site. The testing is expected to investigate the extent to which  
18   tritium released into the atmosphere during the 1950's and 1960's has migrated into the soil at the Ward  
19   Valley site.

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The first part of the paper is devoted to a general discussion of the problem of the origin of the universe. It is shown that the problem is not only a philosophical one, but also a scientific one. The second part of the paper is devoted to a discussion of the various theories of the origin of the universe. It is shown that the various theories are not only different, but also contradictory. The third part of the paper is devoted to a discussion of the various methods of determining the age of the universe. It is shown that the various methods are not only different, but also contradictory.

## CONCLUSION

The conclusion of the paper is that the problem of the origin of the universe is not only a philosophical one, but also a scientific one. The various theories of the origin of the universe are not only different, but also contradictory. The various methods of determining the age of the universe are not only different, but also contradictory. The paper shows that the problem of the origin of the universe is not only a philosophical one, but also a scientific one. The various theories of the origin of the universe are not only different, but also contradictory. The various methods of determining the age of the universe are not only different, but also contradictory.



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1    **4.0        SCOPE OF WORK**

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3    The following is a list of activities that are proposed for the Site Evaluation:

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- 5    • Soil boring/monitoring well installation (coring and drilling) and trenching
- 6    • Multimedia sampling, including groundwater, soils, and investigative-derived waste (IDW)
- 7    • Mobilization/demobilization
- 8    • Site surveying
- 9    • Decontamination of sampling and heavy equipment
- 10   • Maintenance of site equipment

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12   The above listing represents a summarization of the tasks as they apply to the scope and application of

13   this HASP. For a more detailed description of the associated tasks, refer to the Work Plan (WP).

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5.0

TASKS/HAZARDS/ASSOCIATED CONTROL MEASURES

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SUMMARIZATION

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Table 5-1 of this section serves as the primary portion of the site-specific HASP, which identifies the tasks that are to be performed under this HASP. The anticipated hazards, recommended control measures, air-monitoring recommendations, required PPE, and decontamination measures for each site task are discussed in detail. This table and the associated control measures shall be changed if the scope of work, contaminants of concern, or other conditions change. Through using the table, the FOL and field personnel can determine which hazards are associated with each task, what hazards are present at each site, and what associated control measures are necessary to minimize exposure to injuries related to those hazards. The table also assists the FOL in determining which PPE and decontamination procedures to use based on proper air-monitoring techniques and site-specific conditions.

STANDARDIZATION OF THE  
MATHS TEST

The purpose of this study was to determine the reliability and validity of the Maths Test. The test was administered to a group of 100 students in the 10th grade. The results showed that the test was reliable and valid. The reliability coefficient was 0.85 and the validity coefficient was 0.75. The test was found to be a good measure of the students' mathematical ability.



Tasks/Operation/ Locations	Anticipated Hazards	Protective Equipment*	Decontamination Procedures
Soil boring/monitoring well installation and trenching	<p><i>Chemical Hazards</i></p> <p>1) Remote potential for exposure to chlorine-36.</p> <p><i>Physical hazards</i></p> <p>2) Rotating machinery</p> <p>3) Noise</p> <p>4) Energized systems</p> <p>5) Cave-ins</p> <p>6) Slips, trips, and falls</p>	<p>operations are to be conducted.</p> <p>incorporates the following:</p> <p>long pants, long-sleeve shirts</p> <p>shoes</p> <p>will be incorporated as follows:</p> <p>goggles, and earplugs or ear muffs</p> <p><i>worn if there is a risk of exposure to hazardous materials.</i></p> <p><i>Respiratory protection will be incorporated if necessary based on the saturation of work attire.</i></p> <p>change radically, the equipment will be maintained during the project.</p> <p>strategically placed) and first-aid kit</p>	<p><b>Personnel Decontamination</b> - Will consist of a soap/water wash and rinse for outer protective equipment (e.g., boots, gloves, PVC splash suits, etc.). This function will take place at an area adjacent to the drilling operations bordering the support zone.</p> <p>This decontamination procedure for <b>Level D</b> protection will consist of</p> <ul style="list-style-type: none"> <li>- Equipment drop</li> <li>- Soap/water wash and rinse of outer boots</li> <li>- Soap/water wash and rinse of the outer splash suit, as applicable</li> <li>- Outer suit, boot covers, outer glove removal</li> <li>- Wash hands and face; leave contamination reduction zone</li> </ul> <p><b>Equipment Decontamination</b> - All heavy equipment decontamination will take place at a centralized decontamination area utilizing steam or pressure washers. Heavy equipment, such as drill rigs, will have the wheels and tires cleaned along with any loose debris removed, prior to transporting to the central decontamination area. All site vehicles will be restricted access to exclusion zones, or also will have their wheels/tires sprayed off so as not to track mud onto the roadways. Roadways shall be cleared of any debris resulting from the activity.</p> <p>All equipment used in the exclusion zone will require a complete decontamination between locations and prior to removal from the site. The FOL or the SSO will be responsible for evaluating equipment arriving onsite and that which is to leave the site. No equipment will be authorized access or exit without this authorization.</p> <p>Evaluation will consist of</p> <ul style="list-style-type: none"> <li>- Visual inspection</li> </ul>





**TABLE 5-1  
TASKS/HAZARDS/CONTROL MEASURES COMPENDIUM  
WARD VALLEY SITE EVALUATION**

Tasks/Operation/ Locations	Anticipated Hazards	Recommended Control Measures	Hazard Monitoring	Personal Protective Equipment*	Decontamination Procedures
Soil boring/monitoring well installation and trenching	<p><i>Chemical Hazards</i></p> <p>1) Remote potential for exposure to tritium and chlorine-36.</p> <p><i>Physical hazards</i></p> <p>2) Rotating machinery</p> <p>3) Noise</p> <p>4) Energized systems</p> <p>5) Cave-ins</p> <p>6) Slips, trips, and falls</p>	<p>1) Real-time monitoring instrumentation will not detect tritium, and chlorine-36 and therefore will not be used. A PID or FID will be used only as a precaution.</p> <p>2) Decontaminate all equipment and supplies between drilling events and prior to leaving the site.</p> <p>3) All equipment to be used will be</p> <ul style="list-style-type: none"> <li>- Inspected in accordance with Federal safety and transportation guidelines, OSHA (1926.600,.601,.602), and manufacturer's design.</li> <li>- Operated by certified operators, and knowledgeable ground crew.</li> <li>- Used within established safe zones and with clearly demarcated routes of approach</li> </ul> <p>In addition to equipment considerations, the following safe operating procedures will be incorporated:</p> <ul style="list-style-type: none"> <li>- All personnel not directly supporting the drilling operation will remain at least 33 feet from the point of operation.</li> <li>- Drilling, drill masts, or other projecting devices shall be at least 20 feet from overhead power sources and a minimum of 3 feet from underground utilities.</li> <li>- Hand signals will be established prior to the commencement of drilling.</li> <li>- The driller and helper can simultaneously handle moving augers or flights only when there is a standby person to activate the emergency stop device.</li> <li>- The driller must never leave the controls while tools are rotating unless all personnel are clear of the rotating equipment.</li> <li>- A long handled shovel or equivalent shall be used to clear away drill cuttings from the hole and rotating equipment. Hands or feet shall <b>not</b> be used for this purpose.</li> <li>- A remote sampling device must be used to sample drill cuttings near rotating tools. The driller shall shutdown operations if the sampler is near the tools.</li> <li>- Only manufacturer-approved equipment may be used in conjunction with equipment repair procedures (i.e. pins for auger flights etc.).</li> <li>- Never climb a drill mast while equipment is rotating.</li> <li>- Use ANSI-approved fall protection (i.e., belts, lanyards) or portable ladders which meet OSHA's requirements when climbing drill masts.</li> <li>- Work areas will be kept clear of clutter.</li> <li>- Secure all loose articles to avoid possible entanglement.</li> <li>- All equipment shall be equipped with movement warning systems.</li> <li>- All personnel working in high equipment traffic areas are required to wear reflective vests for high visibility.</li> <li>- All personnel will be instructed in the location and operations of the emergency shut-off device(s). This device will be tested initially (and then periodically) to ensure its operational status.</li> <li>- Areas will be inspected prior to the movement of drill rigs and support vehicles to eliminate any physical hazards. This will be the responsibility of the FOL and/or SSO.</li> <li>- Drill rigs and support vehicles will be moved no closer than 3 feet to pits, trenches, etc.</li> </ul> <p>4) Hearing protection will be used during all drilling activities until the SSO can quantify associated noise levels.</p> <p>5) All utility clearances shall be obtained prior to drilling. Prior to any subsurface investigations, the locations of all underground utilities will be identified and marked. Obtain written permit clearance prior to all subsurface investigations.</p> <p>6) No trench entry will be performed or permitted.</p> <p>7) All trenching will be done in accordance with 29CFR1926 subpart P.</p> <p>8) All open trenches will be barricaded at the end of the day.</p>	<p>Photoionization Detector w/ 10.2 eV UV lamp source, or a Flame ionization Detector, will be used as follows:</p> <p>1) Source (borehole, split spoon, and trenching) monitoring will be conducted at regular intervals determined by the SSO. Positive sustained (above background) results which may affect operations crew will require the following actions.</p> <ul style="list-style-type: none"> <li>- Monitor the breathing zone of high-risk employees. Any sustained reading above background in the breathing zone requires evacuation to a safe area until the following measurements can be taken to determine the cause of the reading.</li> </ul>	<p>All drilling and trenching operations are to be initiated in level D protection. Level D protection constitutes the following minimum protection</p> <ul style="list-style-type: none"> <li>- Standard field dress (Long pants, long-sleeve shirts</li> <li>- Steel-toe/shank safety shoes</li> </ul> <p>These following items will be incorporated during drilling operations:</p> <ul style="list-style-type: none"> <li>- Hardhat, safety glasses, and earplugs or muffs.</li> <li>- <i>Tyvek coveralls will be worn if there is a possibility of soiling work attire.</i></li> <li>- <i>PVC or PE coated Tyvek will be incorporated if there is a potential for saturation of work attire.</i></li> </ul> <p>Because conditions may change radically, the following equipment will be maintained during all onsite activities:</p> <ul style="list-style-type: none"> <li>• Fire extinguishers (strategically placed)</li> <li>• Stretcher, blankets, and first-aid kit</li> <li>• Hearing protection</li> <li>• Work gloves</li> </ul>	<p><b>Personnel Decontamination</b> - Will consist of a soap/water wash and rinse for outer protective equipment (e.g., boots; gloves, PVC splash suits, etc.). This function will take place at an area adjacent to the drilling operations bordering the support zone.</p> <p>This decontamination procedure for <b>Level D</b> protection will consist of</p> <ul style="list-style-type: none"> <li>- Equipment drop</li> <li>- Soap/water wash and rinse of outer boots</li> <li>- Soap/water wash and rinse of the outer splash suit, as applicable</li> <li>- Outer suit, boot covers, outer glove removal</li> <li>- Wash hands and face; leave contamination reduction zone</li> </ul> <p><b>Equipment Decontamination</b> - All heavy equipment decontamination will take place at a centralized decontamination area utilizing steam or pressure washers. Heavy equipment, such as drill rigs, will have the wheels and tires cleaned along with any loose debris removed, prior to transporting to the central decontamination area. All site vehicles will be restricted access to exclusion zones, or also will have their wheels/tires sprayed off so as not to track mud onto the roadways. Roadways shall be cleared of any debris resulting from the activity.</p> <p>All equipment used in the exclusion zone will require a complete decontamination between locations and prior to removal from the site. The FOL or the SSO will be responsible for evaluating equipment arriving onsite and that which is to leave the site. No equipment will be authorized access or exit without this authorization.</p> <p>Evaluation will consist of</p> <ul style="list-style-type: none"> <li>- Visual inspection</li> </ul>

\*Items in italics are optional, as conditions dictate or as directed by the FOL or SSO.







**TABLE 5-1  
TASKS/HAZARDS/CONTROL MEASURES COM  
WARD VALLEY SITE EVALUATION  
PAGE 2**

Tasks/Operation/ Locations	Anticipated Hazards	Equipment*	Decontamination Procedures
<p>Multi-media sampling including soils (subsurface); water (groundwater)</p> <p>This activity will be conducted concurrently with soil boring and well installation activities, and will also include IDW sampling activities.</p>	<p><i>Chemical Hazards</i></p> <p>1) Remote potential for exposure to chlorine-36</p> <p><i>Physical hazards</i></p> <p>2) Noise</p> <p>3) Lifting (muscle strains and pulls)</p> <p>4) Pinches and compressions</p> <p>5) Slips, trips, and falls</p>	<p>utilized for the activities.</p> <p>es the following</p> <p>pants, long-sleeve</p> <p>es</p> <p>be incorporated during</p> <p>work gloves, and</p> <p>rn if there is a tire.</p> <p>ill be incorporated if ation of work attire.</p> <p>nant concentrations in this task is not information is based y.</p>	<p><b>Personnel Decontamination</b> will consist of a soap/water wash and rinse for outer protective equipment (e.g. boots, gloves, PVC splash suits, etc.).</p> <p>This function will take place at a satellite location. Disposable PPE will be bagged between sampling events. This procedure will consist of</p> <ul style="list-style-type: none"> <li>- Sample acquisition</li> <li>- Clean (Deionized water spray) the outside of the sample containers/label/bag; ice samples</li> </ul> <p>This decontamination procedure for <b>Level D</b> protection will consist of</p> <ul style="list-style-type: none"> <li>- Equipment drop</li> <li>- Soap/water wash and rinse of outer boots and outer gloves</li> <li>- Soap/water wash and rinse of the outer splash suit, as applicable</li> <li>- Outer suit, boot covers, outer glove removal</li> <li>- Wash hands and face, leave contamination reduction zone</li> </ul> <ul style="list-style-type: none"> <li>- Pack and ice sample transport container</li> </ul>
<p>Mobilization/demobilization</p>	<p><i>Physical Hazards</i></p> <p>1) Lifting (muscle strains and pulls)</p> <p>2) Pinches and compressions</p> <p>3) Slip, trips, and falls</p> <p>4) Moving machinery</p> <p>5) Vehicular and foot traffic</p>	<p>ments)</p> <p>sleeve shirt; long</p> <p>ank)</p> <p>azards exists, or (requirement)</p> <p>affic areas</p> <p>n noise areas, or as operation scenario.</p>	<p>Not required</p>

\*Items in italics are optional, as conditions dictate or a



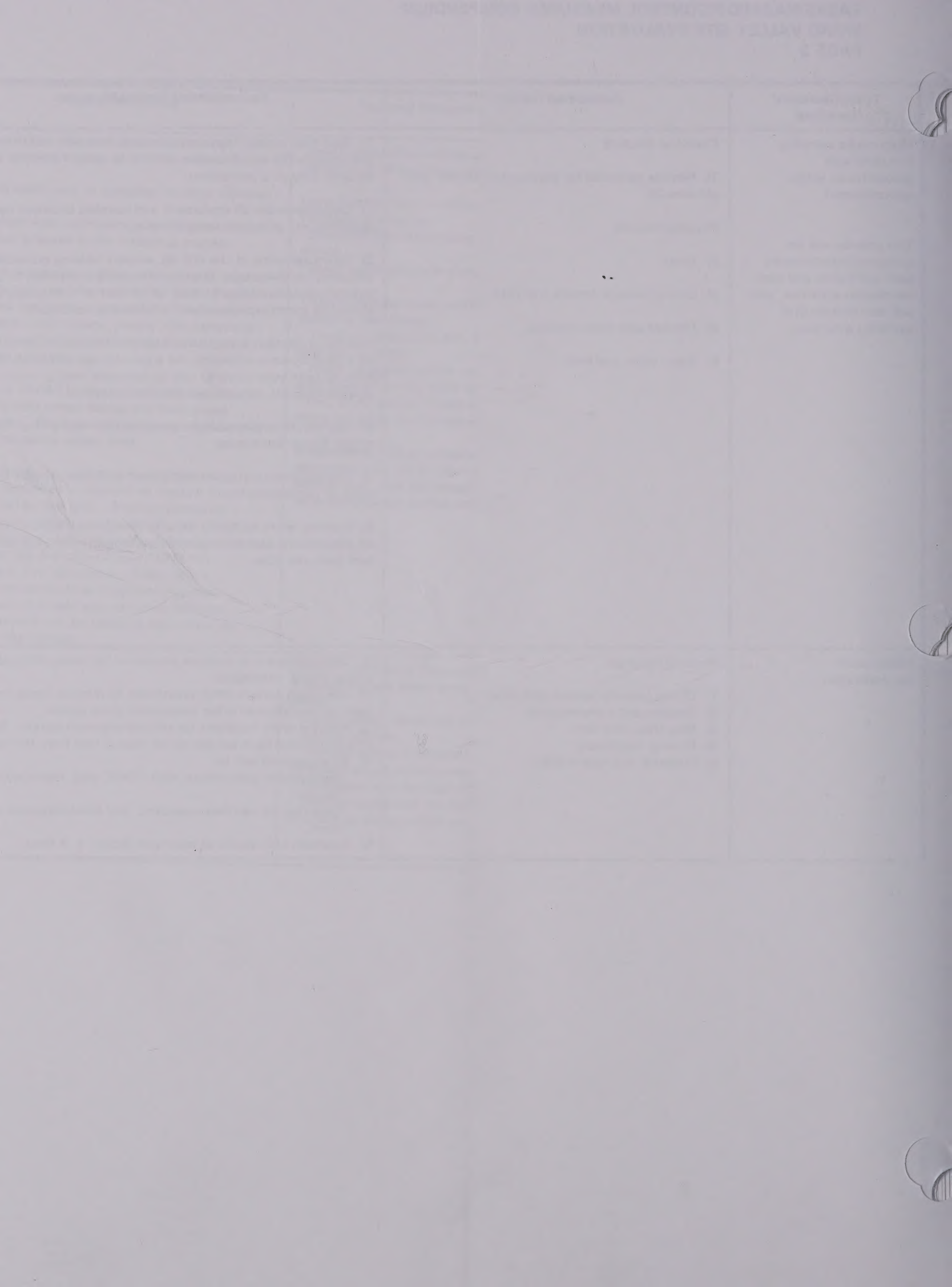


TABLE 5-1  
TASKS/HAZARDS/CONTROL MEASURES COMPENDIUM  
WARD VALLEY SITE EVALUATION  
PAGE 2

Tasks/Operation/ Locations	Anticipated Hazards	Recommended Control Measures	Hazard Monitoring	Personal Protective Equipment*	Decontamination Procedures
<p>Multi-media sampling including soils (subsurface); water (groundwater)</p> <p>This activity will be conducted concurrently with soil boring and well installation activities, and will also include IDW sampling activities.</p>	<p><i>Chemical Hazards</i></p> <p>1) Remote potential for exposure to tritium and chlorine-36</p> <p><i>Physical hazards</i></p> <p>2) Noise</p> <p>3) Lifting (muscle strains and pulls)</p> <p>4) Pinches and compressions</p> <p>5) Slips, trips, and falls</p>	<p>1) Real-time monitoring instrumentation will not detect tritium and chlorine-36 and therefore will not be used. A PID or FID will be used only as a precaution.</p> <p>2) Decontaminate all equipment and supplies between sampling locations and prior to leaving the site.</p> <p>3) When sampling at the drill rig, employ hearing protection as indicated for that task. The use of hearing protection to protect against excessive noise outside of 25 feet of drilling operations should be incorporated under the following condition:</p> <p>Hearing protection during sample acquisition will be determined on a case-by-case scenario. As a general rule of thumb, if you have to raise your voice to talk to someone who is within 2 feet of your location, noise levels may be excessive.</p> <p>4) Use machinery or multiple personnel for heavy lifts. Use proper lifting techniques.</p> <p>5) Use pinch bars or other equipment to remove hands from the point of operation.</p> <p>6) Preview work locations for unstable/uneven terrain. Barricade all excavations and other associated drop-off points at least 3 feet from the edge.</p>	<p>Screen surface soils and groundwater with PID/FID monitor as part of sample acquisition.</p> <p>Open all wells prior to sampling to allow venting.</p> <p>Subsurface soils monitoring direction and action levels will proceed in the following manner.</p> <p>- Source monitoring will be conducted at regular intervals to be determined by the SSO. Positive sustained results at a source location (boreholes, well heads, split spoons, macro core samplers) which may affect operations crew will require the following actions:</p> <p><b>Excessive chemical contaminant concentrations affecting field crews during this task is not anticipated. The following information is based on a contingency action only.</b></p> <p>Source (borehole, split spoon, and trenching) monitoring will be conducted at regular intervals determined by the SSO. Positive sustained (above background) results which may affect operations crew will require the following actions.</p> <p>- Monitor the breathing zone of high-risk employees. Any sustained reading above background in the breathing zone requires evacuation to a safe area until the following measurements can be taken to determine the cause of the reading.</p>	<p>Level D protection will be utilized for the initiation of all sampling activities.</p> <p>Level D protection constitutes the following minimum protection</p> <p>- Standard field dress (long pants, long-sleeve shirts)</p> <p>- Steel toe/shank safety shoes</p> <p>These following items will be incorporated during sampling operations:</p> <p>- <i>Hardhat, safety glasses, work gloves, and earplugs or muffs.</i></p> <p>- <i>Tyvek coveralls will be worn if there is a possibility of soiling work attire.</i></p> <p>- <i>PVC or PE coated Tyvek will be incorporated if there is a potential for saturation of work attire.</i></p> <p><b>Excessive chemical contaminant concentrations impacting field crews during this task is not anticipated. The following information is based on a contingency action only.</b></p>	<p><b>Personnel Decontamination</b> will consist of a soap/water wash and rinse for outer protective equipment (e.g. boots, gloves, PVC splash suits, etc.).</p> <p>This function will take place at a satellite location. Disposable PPE will be bagged between sampling events. This procedure will consist of</p> <p>- Sample acquisition</p> <p>- Clean (Deionized water spray) the outside of the sample containers/label/bag; ice samples</p> <p>This decontamination procedure for <b>Level D</b> protection will consist of</p> <p>- Equipment drop</p> <p>- Soap/water wash and rinse of outer boots and outer gloves</p> <p>- Soap/water wash and rinse of the outer splash suit, as applicable</p> <p>- Outer suit, boot covers, outer glove removal</p> <p>- Wash hands and face, leave contamination reduction zone</p> <p>- Pack and ice sample transport container</p>
Mobilization/ demobilization	<p><i>Physical Hazards</i></p> <p>1) Lifting (muscle strains and pulls)</p> <p>2) Pinches and compressions</p> <p>3) Slip, trips, and falls</p> <p>4) Moving machinery</p> <p>5) Vehicular and foot traffic</p>	<p>1) Use machinery or multiple personnel for heavy lifts. Use proper lifting techniques.</p> <p>2) Use pinch bars or other equipment to remove hands from point of operation or other associated pinch points.</p> <p>3) Preview work locations for unstable/uneven terrain. Barricade all excavations from access closer than 2 feet from the edge.</p> <p>4) All equipment will be</p> <p>- Inspected in accordance with OSHA, and manufacturer's design.</p> <p>- Operated by certified operators, and knowledgeable ground crew.</p> <p>5) Establish safe zones of approach (Boom + 3 feet).</p>	Not required	<p>Level D - (Minimum Requirements)</p> <p>- Standard field attire (long-sleeve shirt; long pants)</p> <p>- Safety shoes (Steel toe/shank)</p> <p>- <i>Safety glasses</i></p> <p>- <i>Hardhat (when overhead hazards exists, or identified as a operation requirement)</i></p> <p>- <i>Reflective vest for high traffic areas</i></p> <p>- <i>Hearing protection for high noise areas, or as directed on an operation by operation scenario.</i></p>	Not required

\*Items in italics are optional, as conditions dictate or as directed by the FOL or SSO.







**TABLE 5-1**  
**TASKS/HAZARDS/CONTROL MEASURES COMP**  
**WARD VALLEY SITE EVALUATION**  
**PAGE 3**

Tasks/Operation/ Locations	Anticipated Hazards	Equipment*	Decontamination Procedures
Site surveying	<i>Physical Hazards</i> 1) Lifting (muscle strains and pulls) 2) Slip, trips, and falls 3) Vehicular traffic	ents) sleeve shirt; long ffic areas noise areas, or as operation scenario.	Not required
Decontamination of sampling and heavy equipment	<i>Chemical Hazards</i> 1) Remote potential for exposure to t chlorine-36 2) Decontamination fluids - Liquinox (c and isopropanol  <i>Physical Hazards</i> 3) Lifting (muscle strains and pulls) 4) Pinches and compressions 5) Flying projectiles 6) Noise	iger flights, etc.): soap/water, steam- cedures. ts - sleeve shirt; long ank) vers liners C coated Tyvek a splash shield anticipated for this  ding trowels, split owing PPE is  ts - sleeve shirt; long ank) r safety glasses  chemical oy PVC rainsuits or necessary.	This decontamination procedure for <b>Level D</b> protection will consist of  - Soap/water wash and rinse of outer gloves - Soap/water wash and rinse of the outer splash suit, as applicable - Wash hands and face
Maintenance of site equipment	<i>Chemical Hazards</i> 1) Remote potential for exposure to t chlorine-36  <i>Physical Hazards</i> 2) Energized systems including pneun electrical, hydraulic, kinetic, and comp	ide by the SSO. protection, as emobilization	Personnel decontamination is not anticipated for this task.

\*Items in italics are optional, as conditions dictate or

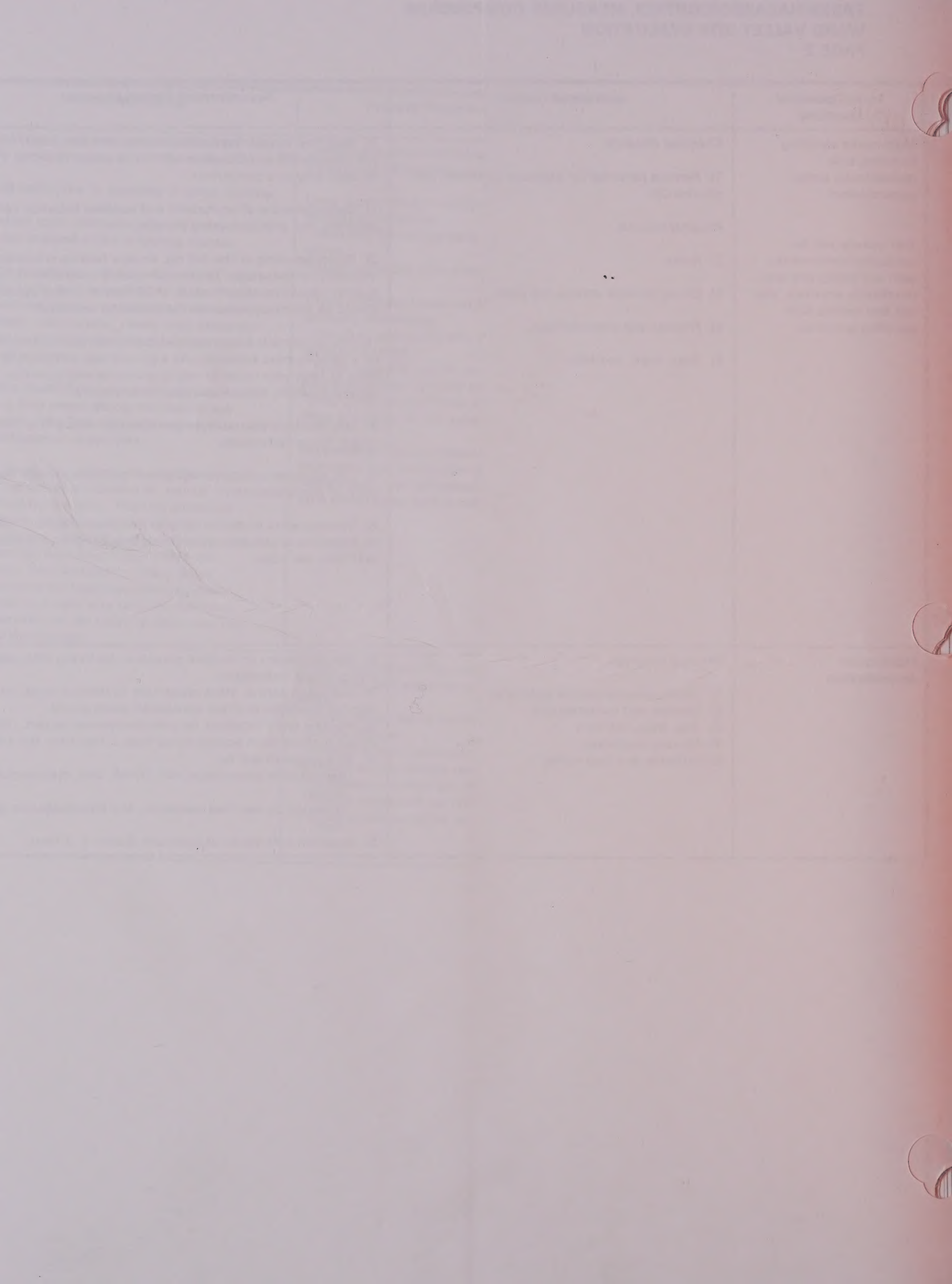




TABLE 5-1  
TASKS/HAZARDS/CONTROL MEASURES COMPENDIUM  
WARD VALLEY SITE EVALUATION  
PAGE 3

Tasks/Operation/ Locations	Anticipated Hazards	Recommended Control Measures	Hazard Monitoring	Personal Protective Equipment*	Decontamination Procedures
Site surveying	<i>Physical Hazards</i>  1) Lifting (muscle strains and pulls) 2) Slip, trips, and falls 3) Vehicular traffic	1) Use machinery or multiple personnel for heavy lifts. Use proper lifting techniques. 2) Preview work locations for unstable/uneven terrain. Maintain a minimum of 3 feet from trenches. 3) Surveying activities conducted in high-traffic areas will require the use of reflective vests and warning signs to inform motorists of the work activity to proceed with caution.	Not required	Level D - (Minimum Requirements) - Standard field attire (Long sleeve shirt; long pants) - <i>Reflective vest for high traffic areas</i> - <i>Hearing protection for high noise areas, or as directed on an operation by operation scenario.</i>	Not required
Decontamination of sampling and heavy equipment	<i>Chemical Hazards</i>  1) Remote potential for exposure to tritium and chlorine-36  2) Decontamination fluids - Liquinox (detergent), and isopropanol  <i>Physical Hazards</i>  3) Lifting (muscle strains and pulls) 4) Pinches and compressions 5) Flying projectiles 6) Noise	1) Employ protective equipment to minimize contact with site contaminants and hazardous decontamination fluids.  2) Ensure that appropriate MSDS sheets from isopropanol manufacturer are on site, and that isopropanol users are familiar and observant of MSDS contents/requirements.  3) Use multiple persons where necessary for lifting and handling heavier pieces of equipment for decontamination purposes.  4) Use care in moving and stacking equipment during and after decontamination activities.  5) Wear eye and face protection when using steam/high pressure washer.  6) Hearing protection will be required when using the steam/high pressure washer.	1) Use visual observation, and real-time monitoring instrumentation specified for the activity that the equipment was used for, to ensure that all equipment has been appropriately cleaned of potentially contaminated medias (e.g. water, soils).	<i>For Heavy Equipment (i.e., auger flights, etc.):</i> This applies to high-pressure soap/water, steam-cleaning, wash and rinse procedures.  Level D minimum requirements - - Standard-field attire (Long-sleeve shirt; long pants) - Safety shoes (Steel toe/shank) - Chemical-resistant boot covers - Nitrile outer gloves, cotton liners - PVC Rainsuits or PE or PVC coated Tyvek - Safety glasses underneath a splash shield  Respiratory protection is not anticipated for this activity.  <i>For sampling equipment including trowels, split spoons, bailers, etc., the following PPE is required:</i>  Level D Minimum requirements - - Standard field attire (Long-sleeve shirt; long pants) - Safety shoes (Steel toe/shank) - Nitrile gloves, cotton liners - Chemical splash goggles or safety glasses with side shields  In the event of overspray of chemical decontamination fluids, employ PVC rainsuits or PE or PVC coated Tyvek as necessary.	This decontamination procedure for <b>Level D</b> protection will consist of  - Soap/water wash and rinse of outer gloves - Soap/water wash and rinse of the outer splash suit, as applicable - Wash hands and face
Maintenance of site equipment	<i>Chemical Hazards</i>  1) Remote potential for exposure to tritium and chlorine-36  <i>Physical Hazards</i>  2) Energized systems including pneumatic, electrical, hydraulic, kinetic, and compressed gas.	1) Use visual observation, real-time monitoring instrumentation, and proper decontamination procedures to ensure all equipment slated for maintenance is properly cleaned of potentially contaminated medias (e.g., air, water, soils).  2) Utilize accepted energy control methods, as defined in 29 CFR 1910.147, to control potential energy sources during maintenance operations. Contact Health Sciences Department for guidance.	Photoionization Detector w/ 10.2 eV UV lamp source or flame ionization detector (FID)  1) Source monitoring will be conducted for evaluation of equipment slated for maintenance by the SSO. Positive sustained results at a source location will require the equipment to be redecontaminated until acceptable levels (no positive indications above background) are obtained.	Selections for PPE will be made by the SSO.  At a minimum, the Level D protection, as defined in the mobilization/demobilization section, will be observed.	Personnel decontamination is not anticipated for this task.

\*Items in italics are optional, as conditions dictate or as directed by the FOL or SSO.



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Section 1.1		Section 2.1	
Section 1.2		Section 2.2	
Section 1.3		Section 2.3	
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## **6.0 HAZARD ASSESSMENT**

The following section provides information regarding the chemical hazards associated with Ward Valley and the activities that are to be conducted as part of the scope of work. Table 6-1, which is included as part of the site-specific HASP, provides various information related to the chemical hazards that may be present at the site. Specifically, toxicological information, exposure limits, symptoms of exposure, physical properties, and air monitoring and sampling data are discussed in the table. Section 6.1 provides general information regarding all contaminants that may be present at the Ward Valley site.

### **6.1 CHEMICAL HAZARDS**

Previous investigations conducted at Ward Valley have indicated that volatile organic compounds are not present. Tritium, chlorine-36, and naturally occurring compounds are the only constituents expected to be present at the site. Cores from drilling and trenching will be screened with a PID/FID as a precaution.

### **6.2 PHYSICAL HAZARDS**

The following physical hazards may be present during the performance of site activities.

- Hazards associated with trenching (cave-ins).
- Contact / entanglement with rotating equipment or machinery.
- Slips, trips, and falls.
- Contact with underground or overhead utilities (electric lines, gas lines, water lines, etc.).
- Strain from heavy lifting.
- Pinch / compression points.
- Noise in excess of 85 decibels (dBA).
- Temperature extremes.
- Other physical hazards associated with ongoing plant operations (proximity to heavy equipment and machinery, vehicular traffic, etc.).

These physical hazards are discussed in detail in Table 5-1 as applicable to each site task.





**TABLE 6-1**  
**CHEMICAL, PHYSICAL, AND TOXICOLOGICAL DATA**  
**WARD VALLEY, CALIFORNIA**

Hazardous Substance	CAS No.	Air Monitoring/Sampling Information		Exposure Limits	Warning Property Rating	Physical Properties	Health Hazard Information
Chlorine-36	NA	NA	NA	NA	NA	Behaves chemically like chlorine	If water containing chlorine-36 is splashed on a person, the contaminated area should be washed immediately with non-contaminated water. Ingestion of the water should be avoided.
Tritium	NA	NA	NA	NA	NA	Behaves chemically like hydrogen	If water containing tritium is splashed on a person, the contaminated area should be washed immediately with non-contaminated water. Ingestion of the water should be avoided.
Diesel fuel * No 2-D	Mixture	Components of this substance will be detected readily by the PID and FID; however, no documentation exists as to the relative response	Air sample using charcoal tube; carbon disulfide desorptions; GC/FID detection. Follow OSHA 07 or NIOSH Method 1500	OSHA PEL NIOSH REL ACGIH TLV-TWA 5 mg/m <sup>3</sup> as mineral oil mist In addition NIOSH and ACGIH establish 10 mg/m <sup>3</sup> as a STEL	Kerosene odor <b>Recommended air purifying cartridges:</b> Organic vapor <b>Recommended gloves:</b> Nitrile	<b>Bolling Pt:</b> <170-400°F; 77-204°C <b>Melting Pt:</b> N.A. <b>Solubility:</b> Negligible <b>Flash Pt:</b> 125°F; 52°C <b>LEL/LFL:</b> 0.6% <b>UEL/UFL:</b> 7.5% <b>Vapor Density:</b> >5 <b>Vapor Pressure:</b> <1 mmHg @ 70°F; 21°C <b>Specific Gravity:</b> 0.86 <b>Incompatibilities:</b> strong oxidizers, halogens, and hypochlorites <b>Appearance and odor:</b> Colorless to amber with a kerosene odor	Prolonged or repeated exposures to this product may cause skin and eye irritation. Because of the defatting capabilities this exposure may lead to a dermatitis condition. High vapor concentrations are irritating to the eyes and respiratory tract. Exposure to high airborne concentrations may result in narcotic effects, including dizziness, headaches, and unconsciousness. High concentrations in a confined space may adequately displace oxygen and thereby result in suffocation.

\* Not a site contaminant





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## 6.2.1 Cold Stress

The following information regarding cold stress will be important when working outside at the Ward Valley site. This information is taken from the “**1997-1998 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Indices**” by the American Conference of Governmental Industrial Hygienists (ACGIH).

### **COLD STRESS**

The cold stress Threshold Limit Values (TLVs) are intended to protect workers from the severest effects of cold stress, also known as hypothermia, and cold injury. They also describe exposures to cold working conditions under which it is believed that workers can be repeatedly exposed to without adverse health effects. The TLV objective is to prevent the deep body temperature from falling below 96.8° F and to prevent cold injury to body extremities (hands, feet and the head). See Table 1.

#### **Introduction**

Fatal exposures to cold among workers have almost always resulted from accidental exposures involving failure to escape from low environmental air temperatures or from immersion in low temperature water. The single most important aspect of life-threatening hypothermia is the fall in the deep core body temperature. This is determined by rectal temperature measurements. Workers should be protected from exposure to cold so that their temperature does not fall below 96.8°F. Lower body temperatures result in reduced mental alertness, reduction in rational decision making, or loss of consciousness with the threat of fatal consequences.

Pain in the extremities may be the first early warning of danger to cold stress. When the body temperature falls to 95°F maximum severe shivering develops. This must be taken as a sign of danger and exposure should be terminated immediately when severe shivering occurs. Continuing to work in these conditions will result in impaired mental and physical work of those affected.

Prolonged exposure to cold air, or to immersion in cold water, at temperatures well above freezing can lead to dangerous hypothermia, whole body protection must be provided.

- Adequate insulating dry clothing to maintain body temperature above 96.8°F must be provided to workers if work is to be performed in air temperatures below 40°F. Wind chill factor is important. The

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1 higher the wind speed and the lower the temperature in the work area the greater the need for well  
2 insulated protective clothing.

- 3
- 4 • Normally cold injuries to the hands, feet, and head occur after the development of the initial signs of  
5 hypothermia. Older workers or workers with circulatory problems require special precautionary  
6 protection. This will usually be requiring extra insulated clothing and/or additional warming periods.
- 7

## 8 **Evaluation and Control**

9

10 It is important to change workers clothes and treat for hypothermia when clothing becomes wet at  
11 temperatures less than 35.6°. There are recommended TLVs for properly clothed workers for periods of  
12 work at temperatures below freezing.

13

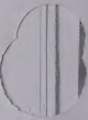
14 Special protection for the hands is required to maintain manual dexterity for the prevention of accidents.

15 If work must be performed more than 10-20 minutes with bare hands in temperatures below 60.8°F,  
16 special precautions such as warm air jets, radiant heaters, etc. should be provided. Otherwise gloves  
17 should be worn.

18

- 19 • Below 19.4°F contact with cold surfaces with bare skin should be avoided.
- 20

- 21 • Below 0°F hands should be protected by mittens. Machine controls and tools should be of a design  
22 so they can be handled without removing mittens.
- 23





---

## **7.0 TRAINING/MEDICAL SURVEILLANCE REQUIREMENTS**

### **7.1 INTRODUCTORY/REFRESHER/SUPERVISORY TRAINING**

This section is included to specify health and safety training and medical surveillance requirements for both TtNUS and subcontractor personnel participating in site activities.

#### **7.1.1 Requirements for TtNUS Personnel**

All TtNUS personnel must complete 40 hours of introductory hazardous waste site training prior to performing work at Ward Valley. Additionally, TtNUS personnel who have had introductory training more than 12 months prior to site work must have completed 8 hours of refresher training within the past 12 months before being cleared for site work. In addition, 8-hour supervisory training in accordance with 29 CFR 1910.120(e)(4) will be required for site supervisory personnel.

Documentation of TtNUS introductory, supervisory, and refresher training as well as site-specific training will be maintained at the project. Copies of certificates or other official documentation will be used to fulfill this requirement.

#### **7.1.2 Requirements for Subcontractors**

All TtNUS subcontractor personnel must have completed introductory hazardous waste site training or equivalent work experience as defined in OSHA Standard 29 CFR 1910.120(e) and 8 hours of refresher training meeting the requirements of 29 CFR 1910.120(e)(8) prior to performing field work at Ward Valley. TtNUS subcontractors must certify that each employee has had such training by sending TtNUS a letter, on company letterhead, containing the information in the example letter provided as in Figure 7-1 and by providing copies of certificates for all subcontractor personnel participating in site activities.

The University of Chicago is a private research university in Chicago, Illinois.

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### THE UNIVERSITY OF CHICAGO

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**FIGURE 7-1**  
**TRAINING LETTER**

The following statements must be typed on company letterhead and signed by an officer of the company and accompanied by copies of personnel training certificates:

LOGO  
XYZ CORPORATION  
555 E. 5th Street  
Nowheresville, Kansas 55555

Month, day, year

Mr. Dennis Beissel  
Task Order Manager  
TtNUS  
910 Clopper Raod  
Gaithersburg, Maryland 20878

Subject: HAZWOPER Training for Ward Valley, California

Dear Mr. Beissel:

As an officer of XYZ Corporation, I hereby state that I am aware of the potential hazardous nature of the subject project. I also understand that it is our responsibility to comply with all applicable occupational safety and health regulations, including those stipulated in Title 29 of the Code of Federal Regulations (CFR), Parts 1900 through 1910 and Part 126.

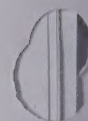
I also understand that Title 29 CFR 1910.120, entitled "Hazardous Waste Operations and Emergency Response," requires an appropriate level of training for certain employees engaged in hazardous waste operations. In this regard, I hereby state that the following employees have had 40 hours of introductory hazardous waste site training or equivalent work experience as requested by 29 CFR 1910.120(e) and have had 8 hours of refresher training as applicable and as required by 29 CFR 1910.120(e)(8) and that site supervisory personnel have had training in accordance with 29 CFR 1910.120(e)(4).

LIST FULL NAMES OF EMPLOYEES AND THEIR SOCIAL SECURITY NUMBERS HERE.

Should you have any questions, please contact me at (555) 555-5555.

Sincerely,

(Name and Title of Company Officer)





---

## 7.2 SITE-SPECIFIC TRAINING

TtNUS will provide site-specific training to all TtNUS employees and subcontractor personnel who will perform work on this project. Site-specific training will also be provided to all personnel who may enter the site to perform functions that may or may not be directly related to site operations. Site-specific training will include:

- Names of designated personnel and alternates responsible for site safety and health
- Safety, health, and other hazards present on site
- Use of personal protective equipment
- Work practices to minimize risks from hazards
- Safe use of engineering controls and equipment
- Medical surveillance requirements
- Signs and symptoms of overexposure
- Contents of the Health and Safety Plan
- Emergency response procedures (evacuation and assembly points)
- Spill response procedures
- Review of the contents of relevant Material Safety Data Sheets

Site-specific documentation will be established through the use of Figure 7-2. All site personnel and visitors must sign this document upon receiving site-specific training.

## 7.3 MEDICAL SURVEILLANCE

### 7.3.1 Medical Surveillance Requirements for TtNUS Personnel

All TtNUS personnel participating in project field activities will have had a physical examination meeting the requirements of TtNUS's medical surveillance program and will be medically qualified to perform hazardous waste site work using respiratory protection

Documentation for medical clearances will be maintained in the TtNUS Gaithersburg office and made available, as necessary.



# THEORY OF THE EARTH

The theory of the earth is a branch of geology which deals with the origin and development of the earth and its various parts. It is a science which seeks to explain the causes of the various geological phenomena which we observe in nature.

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1    **7.3.2            Medical Surveillance Requirements for Subcontractors**

2  
3    Subcontractors are required to obtain a certificate of their ability to perform hazardous waste site work and  
4    to wear respiratory protection. The "Subcontractor Medical Approval Form" provided in Figure 7-3 shall be  
5    used to satisfy this requirement, providing it is properly completed and signed by a licensed physician.  
6

7    Subcontractors who have a company medical surveillance program meeting the requirements of  
8    paragraph (f) of OSHA 29 CFR 1910.120 can substitute "Subcontractor Medical Approval Form" with a  
9    letter, on company letterhead, containing all of the information in the example letter presented in  
10   Figure 7-4 of this HASP.  
11

12   **7.3.3            Requirements for All Field Personnel**

13  
14   Each field team member (including subcontractors) and visitors entering the exclusion zone(s) shall be  
15   required to complete and submit a copy of Medical Data Sheet found in the TtNUS Health and Safety  
16   Guidance Manual. This shall be provided to the SSO, prior to participating in site activities. The purpose  
17   of this document is to provide site personnel and emergency responders with additional information that  
18   may be necessary in order to administer medical attention.  
19

20   **7.4                SUBCONTRACTOR EXCEPTIONS**

21  
22   Subcontractors who will not enter the exclusion zone during operation, and whose activities involve no  
23   potential for exposure to site contaminants, will not be required to meet the requirements for  
24   training/medical surveillance other than site-specific training as stipulated in Section 7.2.  
25

# THE HISTORY OF THE UNITED STATES

The history of the United States is a story of growth and change. It begins with the first settlers who came to the Americas in search of a new life. They found a land of opportunity, but also a land of challenges. The early years were marked by conflict and struggle, but the spirit of the American people was one of resilience and determination.

As the years passed, the United States grew in size and power. It became a nation of immigrants, each bringing their own traditions and customs. The American dream was a powerful force, drawing people from all over the world to the shores of the United States. They sought a better life, a place where they could build a future for themselves and their families.

## THE AMERICAN DREAM

The American dream is the belief that anyone can achieve success and prosperity through hard work and determination. It is a dream that has inspired millions of people to pursue their dreams and to build a better life for themselves. The American dream is a dream of hope and possibility, a dream that has made the United States a land of opportunity for all.

## THE AMERICAN WAY

The American way is a way of life that is based on the principles of freedom, democracy, and individualism. It is a way of life that has made the United States a powerful and influential nation. The American way is a way of life that has inspired people all over the world to strive for a better life and a better future.



FIGURE 7-3

SUBCONTRACTOR MEDICAL APPROVAL FORM

For employees of \_\_\_\_\_  
Company Name

Participant Name: \_\_\_\_\_ Date of Exam: \_\_\_\_\_

**Part A**

The above-named individual has:

1. Undergone a physical examination in accordance with OSHA Standard 29 CFR 1910.120, paragraph (f), and was found to be medically -

- ☐ qualified to perform work at the Ward Valley work site  
☐ not qualified to perform work at the Ward Valley work site

and,

2. Undergone a physical examination in accordance with OSHA 29 CFR 1910.134(b)(10) and was found to be medically -

- ☐ qualified to wear respiratory protection  
☐ not qualified to wear respiratory protection

My evaluation has been based on the following information, as provided to me by the employer.

- ☐ A copy of OSHA Standard 29 CFR 1910.120 and appendices.  
☐ A description of the employee's duties as they relate to the employee's exposures.  
☐ A list of known/suspected contaminants and their concentrations (if known).  
☐ A description of any personal protective equipment used or to be used.  
☐ Information from previous medical examinations of the employee that is not readily available to the examining physician.

**Part B**

I, \_\_\_\_\_, have examined \_\_\_\_\_  
Physician's Name (print) Participant's Name (print)

and have determined the following information:

THE UNIVERSITY OF CHICAGO

CHICAGO, ILL.

June 15, 1964

8

1964

The University of Chicago

Dear Mr. [Name]:

I am pleased to hear that you are interested in the [Topic].

Very truly yours,

[Signature]

[Name]

[Address]

[City, State, Zip]

[Phone Number]

[Fax Number]

1964

[Page Number]

[Page Number]



**FIGURE 7-3**  
**SUBCONTRACTOR MEDICAL APPROVAL FORM**  
**PAGE TWO**

1. Results of the medical examination and tests (excluding finding or diagnoses unrelated to occupational exposure):

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2. Any detected medical conditions which would place the employee at increased risk of material impairment of the employee's health:

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3. Recommended limitations upon the employee's assigned work:

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I have informed this participant of the results of this medical examination and any medical conditions which require further examination or treatment.

Based on the information provided to me, and in view of the activities and hazard potentials involved at the Ward Valley work site, this participant

( ) may  
( ) not

perform his/her assigned task.

Physician's Signature \_\_\_\_\_

Address \_\_\_\_\_

Phone Number \_\_\_\_\_

NOTE: Copies of test results are maintained and available at:

\_\_\_\_\_  
Address

THE UNIVERSITY OF CHICAGO  
LIBRARY

THE UNIVERSITY OF CHICAGO  
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THE UNIVERSITY OF CHICAGO  
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FIGURE 7-4

MEDICAL SURVEILLANCE LETTER

The following statements must be typed on company letterhead and signed by an officer of the company:

LOGO

XYZ CORPORATION

555 E. 5th Street

Nowheresville, Kansas 55555

Month, day, year

Mr. Dennis Beissel

Task Order Manager

TtNUS Corp.

910 Clopper Raod

Gaithersburg, Maryland 20878

Subject: Medical Surveillance for Ward Valley, California

Dear Mr. Beissel:

As an officer of XYZ Corporation, I hereby state that the persons listed below participate in a medical surveillance program meeting the requirements contained in paragraph (f) of Title 29 of the Code of Federal Regulations (CFR), Part 1910.120, entitled "Hazardous Waste Operations and Emergency Response: Final Rule." I further state that the persons listed below have had physical examinations under this program within the past 12 months and that they have been cleared, by a licensed physician, to perform hazardous waste site work and to wear positive- and negative-pressure respiratory protection. I also state that, to my knowledge, no person listed below has any medical restriction that would preclude him/her from working at the Ward Valley, California, site.

LIST FULL NAMES OF EMPLOYEES AND THEIR SOCIAL SECURITY NUMBERS HERE.

Should you have any questions, please contact me at (555) 555-5555.

Sincerely,

(Name and Title of Company Officer)

GENERAL INFORMATION

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## 8.0 SITE CONTROL

This section outlines the means by which TtNUS will delineate work zones and use these work zones in conjunction with decontamination procedures to prevent the spread of contaminants into previously unaffected areas of the site. It is anticipated that a two-zone approach will be used during work at this site: exclusion zone and support zone. It is also anticipated that this control measure will be used to control access to site work areas. Use of such controls will restrict the general public, minimize potentials for the spread of contaminants, and protect individuals who are not cleared to enter the work areas.

### 8.1 EXCLUSION ZONE

The exclusion zones for this project will be limited to those areas of the site where active work is being performed plus so many feet surrounding the point of operation (see Table 5-1 for specific operation). The exclusion zone for each activity will be fragmented to represent the areas where the soils are disturbed through drilling and coring subsurface activities. All exclusion zones will be delineated using barrier tape, cones and/or drive poles, and postings to inform and direct facility personnel.

#### 8.1.1 Exclusion Zone Clearance

A pre-startup site visit will be conducted by members of the identified field team in an effort to identify proposed subsurface investigation locations and provide upfront notices concerning scheduled activities within various sections of Ward Valley.

#### 8.1.2 Site Restoration

To ensure contractors and the general public are not exposed to the dangers involved with this investigation, TtNUS will utilize the following mechanisms as control measures:

- Plastic will be laid down to catch any soil cuttings during the trenching activities as they are generated. Excavated material will be backfilled into the trench once the investigation is complete.



The first part of the report deals with the general situation of the country. It is a very interesting and informative study of the country's development. The second part of the report deals with the specific details of the country's development. It is a very detailed and comprehensive study of the country's development.

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## **8.2 SUPPORT ZONE**

The support zone for this project will include a staging area where site vehicles will be parked, equipment will be unloaded, and where food and drink containers will be maintained. In all cases, the support zones will be established at areas of the site where exposure to site contaminants would not be expected during normal working conditions or foreseeable emergencies.

## **8.3 BUDDY SYSTEM**

Personnel engaged in onsite activities will practice the "buddy system" to ensure the safety of all personnel involved in this operation.

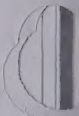
## **8.4 MATERIALS SAFETY DATA SHEET (MSDS) REQUIREMENTS**

TtNUS personnel will provide MSDSs for all chemicals brought on site. The contents of these documents will be reviewed by the SSO with the user(s) of the chemical substances prior to any actual use or application of the substances on site. The MSDSs will then be maintained in a central location (i.e., temporary office) and will be available for anyone to review upon request.

## **8.5 COMMUNICATION**

As personnel may not always be working in proximity to one another during field activities, a supported means of communication between field crews will be used as necessary. Two-way radio communication devices will be used while at the facility. In addition the field operations office will have a cellular telephone.

External communication will be accomplished by using the telephones at predetermined locations or through cellular phones. External communication will primarily be used for the purpose of resource and emergency resource communications. Prior to the commencement of activities at the site, the FOL will determine and arrange for telephone communications, if it is determined a cellular means will not be used.



The first part of the report is a general introduction to the project. It describes the objectives of the study and the methods used to collect and analyze the data. The second part of the report is a detailed description of the results of the study. It includes a discussion of the findings and their implications for the field of research.

The third part of the report is a conclusion and a list of references. The conclusion summarizes the main findings of the study and provides a final assessment of the project. The references list the sources of information used in the study.

The fourth part of the report is a list of appendices. These appendices contain additional information that is relevant to the study but is not included in the main body of the report. They include a list of abbreviations, a list of symbols, and a list of figures.

The fifth part of the report is a list of tables. These tables contain data that is presented in a tabular format. They include a list of tables, a list of figures, and a list of tables.

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## 8.6 SITE VISITORS

Site visitors for the purpose of this document are identified representing the following groups of individuals:

- Personnel invited to observe or participate in operations by TtNUS.
- Regulatory personnel (i.e., BLM, EPA, OSHA, etc.)
- Other authorized visitors

All personnel who require site (areas of ongoing operations) access will be required to obtain permission from the FOL. Upon gaining access to the site, all site visitors wishing to observe operations in progress will be required to meet the following minimum requirements:

- All site visitors will be routed to the FOL, who will sign them in to the field logbook. Information to be recorded in the logbook will include the individual's name (proper identification required), who they represent, and purpose for the visit.
- All site visitors will be required to produce the necessary information supporting clearance onto the site. This includes information attesting to applicable training (40-hours of HAZWOPER training) and to medical surveillance, as stipulated in Section 7.3 of this document. In addition, to enter the site's operational zones during planned activities, all visitors will be required to first go through site-specific training covering the topics stipulated in Section 7.2 of this document.

Following this, the site visitor will be permitted to enter the site and applicable operational areas. All visitors are required to observe the protective equipment and site restrictions in effect at the area of their visit. Any and all visitors not meeting the requirements as stipulated in this plan for site clearance will not be permitted to enter the site operational zones during planned activities. Any incidence of unauthorized site visitation will cause all onsite activities to be terminated until that visitor can be removed. Removal of unauthorized visitors will be accomplished with support from the authorities, if necessary. At a minimum, the project manager will be notified of any unauthorized visitors.





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## 8.7 SITE SECURITY

Site security will involve the implementation of several precautionary measures that will minimize the potential dangers from theft or vandalism. These will include:

- **Security Guards** - Uniformed security guards will be present on a 24 hour per day basis to patrol the work compound and investigation areas. Security guards will report to the TtNUS Project Manager, and will not be armed, but will be authorized to stop and remove unauthorized persons and will patrol all relevant areas of the site. Security guards will be equipped with two-way radios or cellular phones to report disturbances or unusual occurrences to the appropriate authorities.
- **Fencing** - The perimeter of the work compound containing the field office, equipment, and materials will be fenced with an eight foot high chain-link type fence to prevent unauthorized entry of personnel. The TtNUS Project Manager and key personnel will maintain control of access to the compound through a single gate that will be secured by a chain and padlock when personnel are not present.
- **Communication** - Cellular telephones will be present at the site and available to all site personnel to report unusual disturbances or security problems.

The first part of the book is devoted to a general introduction to the subject of the history of the English language. It is a very interesting and useful book for all those who are interested in the history of the English language.

The second part of the book is devoted to a detailed study of the history of the English language from the beginning of the 15th century to the present day. It is a very interesting and useful book for all those who are interested in the history of the English language.

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## 9.0                    CONFINED-SPACE ENTRY

Personnel under the guidance of this HASP will not, under any circumstances, enter confined spaces. A confined space is defined as an area that has all of the following characteristics:

- Is large enough and so configured that an employee can bodily enter and perform assigned work.
- Has limited or restricted means for entry or exit (for example, tanks, manholes, sewers, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
- Is not designed for continuous employee occupancy.

For further information on confined-space operations, consult the Health and Safety Guidance Manual or call the HSM. Any activity that may be considered a confined space entry shall require modifications of this HASP and shall result in the immediate notification of the Project Health and Safety Officer. This determination shall be made by the FOL/SSO.

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## 10.0 MATERIALS AND DOCUMENTATION

The TtNUS FOL shall ensure the following materials/documents are available on the project site and used when required.

- A complete copy of this HASP
- Health and Safety Guidance Manual
- Incident Reports
- Medical Data Sheets
- Material Safety Data Sheets for all chemicals brought on site, including decon solutions, fuels, sample preservatives, calibration gases, etc.
- Follow-up Reports (to be completed by the FOL)
- A full-size OSHA Job Safety and Health Poster (posted in the site trailer)
- Training/Medical Surveillance Documentation Form (Blank)
- First-Aid Supply Usage Form
- Emergency Reference Form (Section 2.0, extra copy for posting)

## 10.1 MATERIALS TO BE POSTED AT THE SITE

The following documentation is to be posted at the site for quick reference purposes. In situations where posting of these documents is not feasible, (such as no office trailer), these documents should be separated and immediately accessible.

**Chemical Inventory Listing** - This list represents all chemicals brought on site, including decontamination solutions, sample preservatives, fuel, etc. This list should be posted in a central area.

**Material Safety Data Sheets (MSDSs)** - The MSDSs should also be in a central area accessible to all site personnel. These documents should match all the listings on the chemical inventory list for all substances employed on site. It is acceptable to have these documents within a central folder and the chemical inventory as the table of contents.

**The OSHA Job Safety & Health Protection Poster** - This poster, as directed by 29 CFR 1903.2 (a)(1), should be conspicuously posted in places where notices to employees are normally posted. Each FOL shall ensure that this poster is not defaced, altered, or covered by other material.





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**Site Clearance Posting** - This list is found within the training section of the HASP (See Figure 7-1). This list identifies all site personnel, dates of training (including site-specific training), and medical surveillance. This list indicates not only clearance but also status. If personnel do not meet these requirements, they do not enter the site while site personnel are engaged in activities.

**Emergency Phone Numbers and Directions to the Hospital** - This list of numbers and the directions will be maintained at all phone communications points and in each site vehicle.

**Medical Data Sheets/Cards** - Medical Data Sheets will be filled out by all onsite personnel and filed in a central location. The Medical Data Sheet will accompany any injury or illness requiring medical attention to the medical facility. A copy of this sheet or a wallet card will be given to all personnel to be carried on their person.

**Hearing Conservation Standard (29 CFR 1910.95)** - This standard will be posted anytime hearing protection or other noise abatement procedures are required.

**Personnel Monitoring** - All results generated through personnel sampling (levels of airborne toxics, noise levels, etc.) will be posted to inform individuals of the results of that effort.

**Placards and Labels** - Where chemical inventories have been separated because of quantities and incompatibilities, these areas will be conspicuously marked using DOT placards and acceptable [Hazard Communication 29 CFR 1910.1200 (f)] labels.

The purpose, as stated above, is to allow site personnel quick access to this information. Variations concerning location and methods of presentation are acceptable, providing the objective is accomplished.

The first part of the paper discusses the importance of the research and the objectives of the study. It also provides a brief overview of the methodology used in the study.

The second part of the paper presents the results of the study. It includes a detailed description of the data collected and the analysis performed.

The third part of the paper discusses the implications of the findings and the conclusions drawn from the study. It also provides recommendations for future research.

The fourth part of the paper provides a summary of the study and its findings. It also includes a list of references and a list of figures and tables.

The fifth part of the paper provides a detailed description of the methodology used in the study. It includes a list of the equipment and materials used and a list of the procedures followed.

The sixth part of the paper provides a detailed description of the data collected and the analysis performed. It includes a list of the data sources and a list of the statistical methods used.

The seventh part of the paper discusses the implications of the findings and the conclusions drawn from the study. It also provides recommendations for future research.



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1	<b>11.0</b>	<b>GLOSSARY</b>
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3	ACGIH	American Conference of Governmental Industrial Hygienists
4	APR	Air-Purifying Respirator
5	ASVE	Air Sparging Vapor Extraction
6	CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
7	CFR	Code of Federal Regulations
8	CNS	Central Nervous System
9	CQP	Construction Quality Plan
10	CRZ	Contamination Reduction Zone
11	EPA	United States Environmental Protection Agency
12	eV	electron Volts
13	FID	Flame Ionization Detector
14	FOL	Field Operations Leader
15	HASP	Health and Safety Plan
16	HAZWOPER	Hazardous Waste Operations and Emergency Response
17	HEPA	High-Efficiency Particulate Air
18	HSM	Health and Safety Manager
19	IDHL	Immediately Dangerous to Life or Health
20	IDW	Investigative Derived Wastes
21	LEL/LFL	lower explosive limit/lower flammable limit
22	MHSP	Master Health and Safety Plan
23	MSDS	Material Safety Data Sheet
24	N/A	Not Available
25	NIOSH	National Institute for Occupational Safety and Health
26	NTP	National Toxicity Program
27	OSHA	Occupational Safety and Health Administration (U.S. Department of Labor)
28	PEL	Permissible Exposure Limit
29	PID	Photoionization Detector
30	PPE	Personal Protective Equipment
31	REL	Recommended Exposure Limits (NIOSH)
32	SCBA	Self-Contained Breathing Apparatus
33	SOPs	standard operating procedures
34	SSO	Site Safety Officer
35	STEL	Short-Term Exposure Limit
36	TBD	To be determined





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1	TLV	Threshold Limit Value (ACGIH)
2	TWA	Time-Weighted Average
3	UEL/UFL	Upper explosive limit/upper flammable limit
4	UV	Ultraviolet
5	WP	Work Plan

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**APPENDIX III**  
**CONTRACTOR MANAGEMENT PLAN**





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**CONTRACTOR MANAGEMENT PLAN**

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**1.0 INTRODUCTION**

**1.1 PURPOSE**

The purpose of the Contractor Management Plan is to define the manner in which contractors will be procured, organized, and managed to provide services for this project. This is an important aspect of the project, because effective contractor management has direct impacts on the efficiency and effectiveness of the project team in completing the work, and compliance with Federal Acquisition Regulations (FAR) is required.

**1.2 SITE AND CONTACT INFORMATION**

All work completed by contractors for this project will be directed by the designated Project Manager (PM) for the project. For the purpose of this project, the 'site' is defined as the property owned by the Bureau of Land Management known as the Ward Valley site, located approximately 20 miles west of Needles, California off Route 40. Other planning documents identify more precisely those areas of the site where field activities will be occurring, and where contractors will be present.

The PM for this project is Mr. Dennis Beissel, PG. Mr. Beissel is responsible for all procurement activity, and will direct the activities of all contractors present at the Ward Valley site. This will include control of entry onto and exit from the site, the conduct of work, and the materials and equipment utilized. Contractors will be required to contact the PM prior to entering the site or performing any site related activities. The PM will be available by telephone or radio during working hours.

**2.0 SUBCONTRACT AWARD AND ADMINISTRATION**

**2.1 IDENTIFYING SOURCES**

Tetra Tech NUS will use a variety of mechanisms to identify appropriate sources for services and materials. These include a computerized vendor database that identifies sources used on previous projects, the use of the Procurement Automated Source System maintained by the U.S. Small Business Administration and the Regional Minority Business Development Centers. TtNUS also has access to files submitted by businesses interested in providing services, supplies and/or equipment.

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## **2.2 PROCUREMENT PROCESS**

Upon recognizing a need for a contractor, the TtNUS PM will complete a requisition in consultation with the project's Contract Administrator. The planning is reviewed and approved by relevant personnel, and includes basic information such as type of procurement, type of subcontract, period of performance, scope of work, deliverables, and technical evaluation criteria. The procurement planning document will include a planning schedule that indicates target and actual dates for all phases of the procurement process.

## **2.3 ISSUING SOLICITATIONS**

Solicitation packages will include technical specifications, statement of work, instructions to offerors, and terms and conditions (including government flow-down clauses). Packages will also include requirements for Health and Safety, Quality Assurance/Quality Control, training, and other appropriate clauses.

## **2.4 SOURCE SELECTION AND AWARD**

Proposals are received and evaluated against evaluation criteria in conjunction with independent estimates. Each proposal is evaluated to determine responsiveness to proposal requirements, completeness, and accuracy. In addition, each proposal is evaluated to determine technical and financial responsibility of the offeror. A cost analysis is performed based on the information obtained from the offeror. A contractor will be selected subsequent to review of all offers. TtNUS will make certain that awards are reasonably priced, technically and financially responsible, and responsive to the scope of work.

The TtNUS Contract Administrator, with the assistance of the PM, will conduct any needed price negotiations with the apparent successful offeror. The Contract Administrator will prepare a subcontract agreement with the successful offeror. If necessary, procurement personnel will request Government consent on the subcontract package. Following consent, procurement personnel will award the contract. All phases of the source selection and award process will be documented in writing and maintained in a separate subcontract file.

For non-competitive awards, TtNUS will submit a Justification for Noncompetitive Procurement to the Government Contracting Officer. TtNUS recognizes the Government must reasonably conclude that a need can only be satisfied by a single source.

The scientific method is a systematic approach to the study of the natural world. It involves the formulation of a hypothesis, the design of an experiment, the collection of data, and the analysis of the results. The scientific method is a process that is used to test the validity of a hypothesis. It is a process that is used to determine whether a hypothesis is supported by the evidence. The scientific method is a process that is used to determine whether a hypothesis is supported by the evidence.

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## 2.5 MONITORING AND ASSESSING CONTRACTOR PERFORMANCE

The TtNUS Contract Administrator maintains overall responsibility for the award, administration, and timely closeout of all subcontracts required in support of program activities. The PM will ensure that key members of the project team are involved in monitoring technical, managerial, and financial performance of subcontractors. The PM is responsible for assuring that subcontractors prepare all deliverables in compliance with subcontract agreements. The Contract Administrator will monitor compliance with all contractual and financial requirements of the subcontract agreements.

## 2.6 SMALL PURCHASES

Small purchase procedures are applied to the purchase of goods and services directly and indirectly in support of program activities, resulting in the issuance of purchase orders. A purchase order mechanism will be used where special liability, warranty, insurance, and other special provisions are not necessary to protect TtNUS interests. TtNUS is committed to utilizing small, small disadvantaged, and women-owned businesses to the extent practicable in fulfilling small purchase requirements.

Purchases of \$2,500 or less will be initiated through the execution of a purchase requisition and may be made without securing competitive prices if a determination can be made that the price is reasonable based on comparisons to current catalog prices, previous prices paid, comparison to similar items, or personal knowledge. A Price Reasonableness Determination will be executed and maintained as part of the purchase order file. If it is necessary to obtain competitive bids to determine price reasonableness, they will be recorded on an Abstract of Bids. Such purchases will be distributed equitably among qualified vendors.



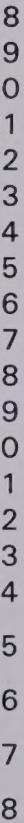


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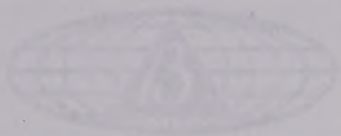
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BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

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03/01/00	0
Approved	
B&R Environmental, Inc.	
Prepared	
Earth Sciences Department	
Reviewed	
B. Campbell	

EVALUATION OF EXISTING MONITORING WELLS  
AND WATER LEVEL MEASUREMENT

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### APPENDIX IV

### BRE STANDARD OPERATING PROCEDURES

THE STANDARD & EVALUATION PROCEDURE  
APPLYING IN





# STANDARD OPERATING PROCEDURES

BROWN & ROOT ENVIRONMENTAL

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03/01/96

Revision  
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Applicability  
B&R Environmental, NE

Prepared  
Earth Sciences Department

Subject  
EVALUATION OF EXISTING MONITORING WELLS  
AND WATER LEVEL MEASUREMENT

Approved  
D. Senovich

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## 1.0 PURPOSE

The purpose of this procedure is to provide reference information regarding the proper methods for evaluating existing monitoring wells, and determining water level measurements.

## 2.0 SCOPE

The procedures described herein are applicable to all existing monitoring wells and, for the most part, are independent of construction materials and methods.

## 3.0 GLOSSARY

Hydraulic Head - The height to which water will rise in a well.

Water Table - A surface in an unconfined aquifer where groundwater pressure is equal to atmospheric pressure (i.e., the pressure head is zero).

## 4.0 RESPONSIBILITIES

Site Geologist/Hydrogeologist - Has overall responsibility for obtaining water level measurements and developing groundwater contour maps. The site geologist/hydrogeologist (in concurrence with the Project Manager) shall specify the reference point from which water levels are measured (usually a specific point on the upper edge of the inner well casing), the number of data points needed and which wells shall be used for a contour map, and how many complete sets of water levels are required to adequately define groundwater flow directions (e.g., if there are seasonal variations).

Field Personnel - Must have a basic familiarity with the equipment and procedures involved in obtaining water levels, and must be aware of any project-specific requirements.

## 5.0 PROCEDURES

Accurate, valid and useful groundwater monitoring requires that four important conditions be met:

- Proper characterization of site hydrogeology.
- Proper design of the groundwater monitoring program, including adequate numbers of wells installed at appropriate locations and depths.
- Satisfactory methods of groundwater sampling and analysis to meet the data quality objectives (DQOs).
- The assurance that specific monitoring well samples are representative of water quality conditions in the monitored interval.

To insure that these conditions are met, adequate descriptions of subsurface geology, well construction methods and well testing results must be available. The following steps will help to insure that the required data are available to permit an evaluation of the utility of existing monitoring wells for collecting additional samples.



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## 5.1 Preliminary Evaluation

A necessary first step in evaluating existing monitoring well data is the study and review of the original work plan for monitoring well installation (if available). This helps to familiarize the site geologist/hydrogeologist with site-specific conditions, and will promote an understanding of the original purpose of the monitoring wells.

The next step of the evaluation should involve a review of all available information concerning borehole drilling and well construction. This will allow interpretation of groundwater flow conditions and area geology, and will help to establish consistency between hydraulic properties of the well and physical features of the well or formation. The physical features which should be identified and detailed, if available, include:

- The well identification number, permit number and location by referenced coordinates, the distance from prominent site features, or the location of the well on a map.
- The installation dates, drilling methods, well development methods, and contractors.
- The depth to bedrock -- where rock cores were not taken, auger refusal, drive casing refusal or penetration test results (blow counts for split-barrel sampling) may be used to estimate bedrock interface.
- The soil profile and stratigraphy.
- The borehole depth and diameter.
- The elevation of the top of the protective casing, the top of the well riser, and the ground surface.
- The total depth of the well.
- The type of well materials, screen type, slot size, and length, and the elevation/depths of the screen, interval, and/or monitored interval.
- The elevation/depths of the tops and bottom of the filter pack and well seals and the type and size.

## 5.2 Field Inspection

During the onsite inspection of existing monitoring wells, features to be noted include:

- The condition of the protective casing, cap and lock.
- The condition of the cement seal surrounding the protective casing.
- The presence of depressions or standing water around the casing.
- The presence of any electrical cable and its connections.

If the protective casing, cap and lock have been damaged or the cement collar appears deteriorated, or if there are any depressions around the well casing capable of holding water, surface water may have



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infiltrated into the well. This may invalidate previous sampling results since the time when leakage started is unknown.

The routine physical inspection must be followed by a more detailed investigation to identify other potential routes of contamination or sampling equipment malfunction. Any of these occurrences may invalidate previously-collected water quality data. If the monitoring well is to be used in the future, considerations shown in the steps described above should be rectified to rehabilitate the well. After disconnecting any wires, cables or electrical sources, remove the lock and open the cap. Check for the presence of organic vapors with a photoionization detector (PID) or flame-ionization detector (FID) and combustible gas meter to determine the appropriate worker safety level. The following information should be noted:

- Cap function.
- Physical characteristics and composition of the inner casing or riser, including inner diameter and annular space.
- Presence of grout between the riser and outer protective casing and the existence of drain holes in the protective casing.
- Presence of a riser cap, method of attachment to casing, and venting of the riser.
- Presence of dedicated sampling equipment; if possible, remove such equipment and inspect size, materials of construction and condition.

The final step of the field inspection is to confirm previous hydraulic or physical property data and to obtain data not previously available. This includes the determination of static water levels, total well depth and well obstruction. This may be accomplished using a weighted tape measure which can also be used to check for sediment (the weight will advance slowly if sediment is present, and the presence of sediment on the weight upon removal should be noted). If sediment is present, the well should be redeveloped before sampling.

Lastly, as a final step, the location, condition and expected water quality of the wells should be reviewed in light of their usefulness for the intended purpose of the investigation.

### **5.3 Water Level (Hydraulic Head) Measurements**

#### **5.3.1 General**

Groundwater level measurements can be made in monitoring wells, private or public water wells, piezometers, open boreholes, or test pits (after stabilization). Groundwater measurements should generally not be made in boreholes with drilling rods or auger flights present. If groundwater sampling activities are to occur, groundwater level measurements shall take place prior to well evacuation or sampling.

All groundwater level measurements shall be made to the nearest 0.01 foot, and recorded in the site geologist/hydrogeologist's field notebook or on the Groundwater Level Measurement Sheet (Attachment A), along with the date and time of the reading. The total depth of the well shall be measured and recorded, if not already known. Weather changes that occur over the period of time during which water levels are being taken, such as precipitation and barometric pressure changes, should be noted.



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In measuring groundwater levels, there shall be a clearly-established reference point of known elevation, which is normally identified by a mark on the upper edge of the inner well casing. The reference point shall be noted in the field notebook. To be useful, the reference point should be tied in with an established USGS benchmark or other properly surveyed elevation datum. An arbitrary datum could be used for an isolated group of wells, if necessary.

Cascading water within a borehole or steel well casings can cause false readings with some types of sounding devices (chalked line, electrical). Oil layers may also cause problems in determining the true water level in a well. Special devices (interface probes) are available for measuring the thickness of oil layers and true depth to groundwater, if required.

Water level readings shall be taken regularly, as required by the site geologist/hydrogeologist. Monitoring wells or open-cased boreholes that are subject to tidal fluctuations should be read in conjunction with a tidal chart (or preferably in conjunction with readings of a tide staff or tide level recorder installed in the adjacent water body); the frequency of such readings shall be established by the site hydrogeologist. All water level measurements at a site used to develop a groundwater contour map shall be made in the shortest practical time to minimize affects due weather changes, and at least during the same day.

### 5.3.2 Water Level Measuring Techniques

There are several methods for determining standing or changing water levels in boreholes and monitoring wells. Certain methods have particular advantages and disadvantages depending upon well conditions. A general description of these methods is presented, along with a listing of various advantages and disadvantages of each technique. An effective technique shall be selected for the particular site conditions by the site geologist/hydrogeologist.

In most instances, preparation of accurate potentiometric surface maps require that static water level measurements be obtained to a precision of 0.01 feet. To obtain such measurements in individual accessible wells, chalked tape or electrical water level indicator methods have been found best, and thus are the most often utilized. Other, less precise methods, such as the popper or bell sound, or bailer line methods, may be appropriate for developing preliminary estimates of hydraulic conditions. When a large number of (or continuous) readings are required, time-consuming individual readings are not usually feasible. In such cases, it is best to use the float recorder or pressure transducer methods. When conditions in the well limit readings (i.e., turbulence in the water surface or limited access through small diameter tubing), less precise, but appropriate methods such as the air line or capillary tubing methods can be used (see subsequent SOP section for discussion of these devices).

### 5.3.3 Methods

Water levels can be measured by several different techniques, but the same steps shall be followed in each case. The proper sequence is as follows:

1. Check operation of recording equipment above ground. Prior to opening the well, don personal protective equipment, as required.
2. Record all information specified below in the geologist/hydrogeologist's field notebook or on the Groundwater Level Measurement Sheet (Attachment A):
  - Well number.



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- Water level (to the nearest 0.01 foot; 0.3 cm). Water levels shall be taken from the surveyed reference mark on the top edge of the inner well casing.
- Time and day of the measurement.

Water level measuring devices with permanently marked intervals shall be used when possible. If water level measuring devices marked by metal or plastic bands clamped at intervals along the measuring line are used, the spacing and accuracy of these bands shall be checked frequently as they may loosen and slide up or down the line, resulting in inaccurate reference points.

#### 5.3.4 Water Level Measuring Devices

##### Chalked Steel Tape

The water level is measured by chalking a weighted steel tape and lowering it a known distance (to any convenient whole foot mark) into the well or borehole. The water level is determined by subtracting the wetted chalked mark from the total length lowered into the hole.

The tape shall be withdrawn quickly from the well because water has a tendency to rise up the chalk due to capillary action. A water finding paste may be used in place of chalk. The paste is spread on the tape the same way as the chalk, and turns red upon contacting water.

Disadvantages to this method include the following: depths are limited by the inconvenience of using heavier weights to properly tension longer tape lengths; ineffective if borehole/well wall is wet or inflow is occurring above the static water level; chalking the tape is time-consuming; difficult to use during periods of precipitation.

##### Electric Water Level Indicators

These devices consist of a spool of small-diameter cable and a weighted probe attached to the end. When the probe comes in contact with the water, an electrical circuit is closed and a meter, light, and/or buzzer attached to the spool will signal the contact.

There are a number of commercial electric sounders available, none of which is entirely reliable under all conditions likely to occur in a contaminated monitoring well. In conditions where there is oil on the water, groundwater with high specific conductance, water cascading into the well, steel well casing, or a turbulent water surface in the well, measuring with an electric sounder may be difficult.

For accurate readings, the probe shall be lowered slowly into the well. The electric tape is marked at the measuring point where contact with the water surface was indicated. The distance from the mark to the nearest tape band is measured using an engineer's folding ruler or steel tape, and added to the band reading to obtain the depth to water. If the band is not a permanent marking band, spacing shall be checked periodically as described in Section 5.3.6.

##### Popper or Bell Sounder

A bell- or cup-shaped weight that is hollow on the bottom is attached to a measuring tape and lowered into the well. A "plopping" or "popping" sound is made when the weight strikes the surface of the water. An accurate reading can be determined by lifting and lowering the weight in short strokes, and reading the tape when the weight strikes the water. This method is not sufficiently accurate to obtain water levels to 0.01 feet, and thus is more appropriate for obtaining only approximate water levels quickly.



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### Float Recorder

A float or an electromechanically actuated water-seeking probe may be used to detect vertical changes of the water surface in the hole. A paper-covered recording chart drum is rotated by the up and down motion of the float via a pulley and reduction gear mechanism, while a clock drive moves a recording pen horizontally across the chart. To ensure continuous records, the recorder shall be inspected, maintained, and adjusted periodically. This type of device is useful for continuously measuring periodic water level fluctuations, such as tidal fluctuations or influences of pumping wells.

### Air Line

An air line is especially useful in pumped wells where water turbulence may preclude the use of other devices. A small-diameter weighted tube of known length is installed from the surface to a depth below the lowest water level expected. Compressed air (from a compressor, bottled air, or air pump) is used to purge the water from the tube, until air begins to escape the lower end of the tube, and is seen (or heard) to be bubbling up through the water in the well. The pressure needed to purge the water from the air line multiplied by 2.307 (feet of water for 1 psi) equals the length in feet of submerged air line. The depth to water below the center of the pressure gauge can be calculated by subtracting the length of air line below the water surface from the total length of the air line.

The disadvantages to this method include the need for an air supply and lower level of accuracy (unless a very accurate air pressure gauge is used, this method cannot be used to obtain water level readings to the nearest 0.01 ft).

### Capillary Tubing

In small diameter piezometer tubing, water levels are determined by using a capillary tube. Colored or clear water is placed in a small "U"-shaped loop in one end of the tube (the rest of the tube contains air). The other end of the capillary tube is lowered down the piezometer tubing until the water in the loop moves, indicating that the water level has been reached. The point is then measured from the bottom of the capillary tube or recorded if the capillary tube is calibrated. This is the best method for very small diameter tubing monitoring systems such as Barcad and other multilevel systems. Unless the capillary tube is calibrated, two people may be required to measure the length of capillary tubing used to reach the groundwater. Since the piezometer tubing and capillary tubing usually are somewhat coiled when installed, it is difficult to accurately measure absolute water level elevations using this method. However, the method is useful in accurately measuring differences or changes in water levels (i.e., during pumping tests).

### Pressure Transducer

Pressure transducers can be lowered into a well or borehole to measure the pressure of water and therefore the water elevation above the transducer. The transducer is wired into a recorder at the surface to record changes in water level with time. The recorder digitizes the information and can provide a printout or transfer the information to a computer for evaluation (using a well drawdown/recovery model). The pressure transducer should be initially calibrated with another water level measurement technique to ensure accuracy. This technique is very useful for hydraulic conductivity testing in highly permeable material where repeated, accurate water level measurements are required in a very short period of time. A sensitive transducer element is required to measure water levels to 0.01 foot accuracy.



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## **Borehole Geophysics**

Approximate water levels can be determined during geophysical logging of the borehole (although this is not the primary purpose for geophysical logging and such logging is not cost effective if used only for this purpose). Several logging techniques will indicate water level. Commonly-used logs which will indicate saturated/unsaturated conditions include the spontaneous potential (SP) log and the neutron log.

### **5.3.5 Data Recording**

Water level measurements, time, data, and weather conditions shall be recorded in the geologist/hydrogeologist's field notebook or on the Groundwater Level Measurement Sheet. All water level measurements shall be measured from a known reference point. The reference point is generally a marked point on the upper edge of the inner well casing that has been surveyed for an elevation. The exact reference point shall be marked with permanent ink on the casing since the top of the casing may not be entirely level. It is important to note changes in weather conditions because changes in the barometric pressure may affect the water level within the well.

### **5.3.6 Specific Quality Control Procedures for Water Level Measuring Devices**

All groundwater level measurement devices must be cleaned before and after each use to prevent cross contamination of wells. Manufacturer's instructions for cleaning the device shall be strictly followed. Some devices used to measure groundwater levels may need to be calibrated. These devices shall be calibrated to 0.01 foot accuracy and any adjustments/corrections shall be recorded in the field logbook/notebook. After the corrections/adjustments are made to the measuring device and entered in the field logbook/notebook, the corrected readings shall be entered onto the Groundwater Level Measurement Sheet (Attachment A). Elevations will be entered on the sheet when they become available.

### **5.4 Health and Safety Considerations**

Groundwater contaminated by volatile organic compounds may release toxic vapors into the air space inside the well pipe. The release of this air when the well is initially opened is a health/safety hazard which must be considered. Initial monitoring of the well headspace and breathing zone concentrations using a PID (e.g., HNu) or FID (e.g., OVA) and combustible gas meters shall be performed to determine required levels of protection.

## **6.0 RECORDS**

A record of all field procedures, tests and observations must be recorded in the site logbook or designated field notebook. Entries in the log/notebook should include the individuals participating in the field effort, and the date and time. The use of annotated sketches may help to supplement the evaluation.

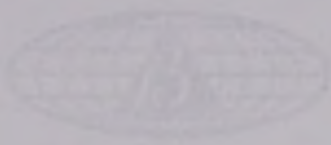












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SOE AND SOE DRILLING METHODS

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## 1.0 PURPOSE

The purpose of this procedure is to describe the methods and equipment necessary to perform soil and rock borings and identify the equipment, sequence of events, and appropriate methods necessary to obtain soil, both surface and subsurface, and rock samples during field sampling activities.

## 2.0 SCOPE

This guideline addresses most of the accepted and standard drilling techniques, their benefits, and drawbacks. It should be used generally to determine what type of drilling techniques would be most successful depending on site-specific geologic conditions and the type of sampling required:

The sampling methods described within this procedure are applicable to collecting surface and subsurface soil samples, and obtaining rock core samples for lithologic and hydrogeologic evaluation, excavation/foundation design and related civil engineering purposes.

## 3.0 GLOSSARY

Rock Coring - A method in which a continuous solid cylindrical sample of rock or compact rock-like soil is obtained by the use of a double tube core barrel that is equipped with an appropriate diamond-studded drill bit which is advanced with a hydraulic rotary drilling machine.

Wire-Line Coring - As an alternative to conventional coring, this technique is valuable in deep hole drilling, since this method eliminates trips in and out of the hole with the coring equipment. With this technique, the core barrel becomes an integral part of the drill rod string. The drill rod serves as both a coring device and casing.

## 4.0 RESPONSIBILITIES

Project Manager - In consultation with the project geologist, the Project Manager is responsible for evaluating the drilling requirements for the site and specifying drilling techniques that will be successful given the study objectives and geologic conditions at the site. The Project Manager also determines the disposal methods for products generated by drilling, such as drill cuttings and well development water, as well as any specialized supplies or logistical support required for the drilling operations.

Field Operations Leader (FOL) - The FOL is responsible for the overall supervision and scheduling of drilling activities, and is strongly supported by the project geologist.

Project Geologist - The project geologist is responsible for ensuring that standard and approved drilling procedures are followed. The geologist will generate a detailed boring log for each test hole. This log shall include a description of materials, samples, method of sampling, blow counts, and other pertinent drilling and testing information that may be obtained during drilling (see SOPs SA-6.3 and GH-1.5). Often this position for inspecting the drilling operations may be filled by other geotechnical personnel, such as soils and foundation engineers, civil engineers, etc.

Determination of the exact location for borings is the responsibility of the site geologist. The final location for drilling must be properly documented on the boring log. The general area in which the borings are to be located will be shown on a site map included in the Work Plan and/or Sampling and Analysis Plan.



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Drilling Subcontractor - Operates under the supervision of the FOL. Responsible for obtaining all drilling permits and clearances, and supplying all services (including labor), equipment and material required to perform the drilling, testing, and well installation program, as well as maintenance and quality control of such required equipment except as stated in signed and approved subcontracts.

The driller must report any major technical or analytical problems encountered in the field to the FOL within 24 hours of determination, and must provide advance written notification of any changes in field procedures, describing and justifying such changes. No such changes shall be made unless requested and authorized in writing by the FOL (with the concurrence of the Project Manager).

The drilling subcontractor is responsible for following decontamination procedures specified in the project plan documents. Upon completion of the work, the driller is responsible for demobilizing all equipment, cleaning up any materials deposited on site during drilling operations, and properly backfilling any open borings.

## 5.0 PROCEDURES

### 5.1 General

The purpose of drilling boreholes is:

- To determine the type, thickness, and certain physical and chemical properties of the soil, water and rock strata which underlie the site.
- To install monitoring wells or piezometers.

All drilling and sampling equipment will be cleaned between samples and borings using appropriate decontamination procedures as outlined in SOP SA-7.1. Unless otherwise specified, it is generally advisable to drill borings at "clean" locations first, and at the most contaminated locations last, to reduce the risk of spreading contamination between locations. All borings must be logged by the rig geologist as they proceed (see SOPs SA-6.3 and GH-1.5). Situations where logging would not be required would include installation of multiple well points within a small area, or a "second attempt" boring adjacent to a boring that could not be continued through resistant material. In the latter case, the boring log can be resumed 5 feet above the depth at which the initial boring was abandoned, although the rig geologist should still confirm that the stratigraphy at the redrilled location conforms essentially with that encountered at the original location. If significant differences are seen, each hole should be logged separately.

### 5.2 Drilling Methods

The selected drilling methods described below apply to drilling in subsurface materials, including, but not limited to, sand, gravel, clay, silt, cobbles, boulders, rock and man-made fill. Drilling methods should be selected after studying the site geology and terrain, the waste conditions at the site, and reviewing the purpose of drilling and the overall subsurface investigation program proposed for the site. The full range of different drilling methods applicable to the proposed program should be identified with final selection based on relative cost, availability, time constraints, and how well each method meets the sampling and testing requirements of the individual drilling program.



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### 5.2.1 Continuous-Flight Hollow-Stem Auger Drilling

This method of drilling consists of rotating augers with a hollow stem into the ground. Cuttings are brought to the surface by the rotating action of the auger. This method is relatively quick and inexpensive. Advantages of this type of drilling include:

- Samples can be obtained without pulling the augers out of the hole. However, this is a poor method for obtaining grab samples from thin, discrete formations because of mixing of soils which occurs as the material is brought to the surface. Sampling of such formations requires the use of split-barrel or thin-wall tube samplers advanced through the hollow core of the auger.
- No drilling fluids are required.
- A well can be installed inside the auger stem and backfilled as the augers are withdrawn.

Disadvantages and limitations of this method of drilling include:

- Augering can only be done in unconsolidated materials.
- The inside diameter of hollow stem augers used for well installation should be at least 4 inches greater than the well casing. Use of such large-diameter hollow-stem augers is more expensive than the use of small-diameter augers in boreholes not used for well installation. Furthermore, the density of unconsolidated materials and depths become more of a limiting factor. More friction is produced with the larger diameter auger and subsequently greater torque is needed to advance the boring.
- The maximum effective depth for drilling is 150 feet or less, depending on site conditions and the size of augers used.
- In augering through clean sand formations below the water table, the sand will tend to flow into the hollow stem when the plug is removed for soil sampling or well installation. If the condition of "running" or "flowing" sands is persistent at a site, an alternative method of drilling is recommended, in particular for wells or boreholes deeper than 25 feet.
- Hollow-stem auger drilling is the preferred method of drilling. Most alternative methods require the introduction of water or mud downhole (air rotary is the exception) to maintain the open borehole. With these other methods, great care must be taken to ensure that the method does not interfere with the collection of a representative sample (which is the objective of the borehole construction. With this in mind, the preferred order of choice of drilling method after hollow-stem augering (HSA) is:
  - Cable tool
  - Casing drive (air)
  - Air rotary
  - Mud rotary
  - Rotasonic
  - Drive and wash
  - Jetting



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However, the use of any method will also depend on efficiency and cost-effectiveness. In many cases, mud rotary is the only feasible alternative to hollow-stem augering. Thus, mud rotary drilling is generally acceptable as a first substitute for HSA.

The procedures for sampling soils through holes drilled by hollow-stem auger shall conform with the applicable ASTM Standards: D1587-83 and D1586-84. The guidelines established in SOP SA-1.3 shall also be followed. The hollow-stem auger may be advanced by any power-operated drilling machine having sufficient torque and ram range to rotate and force the auger to the desired depth. The machine must, however, be equipped with the accessory equipment needed to perform required sampling, or rock coring.

The hollow-stem auger may be used without the plug when boring for geotechnical examination or for well installation. However, when drilling below the water table, specially designed plugs which allow passage of formation water but not solid material shall be used (see Reference 1 of this guideline). This drilling configuration method also prevents blow back and plugging of the auger when the plug is removed for sampling.

Alternately, it may be necessary to keep the hollow stem full of water, at least to the level of the water table, to prevent blowback and plugging of the auger. If water is added to the hole, it must be sampled and analyzed to determine if it is free from contaminants prior to use. In addition, the amount of water introduced, the amount recovered upon attainment of depth, and the amount of water extracted during well development must be carefully logged in order to ensure that a representative sample of the formation water can be obtained. Well development should occur as soon after well completion as practicable (see SOP GH-2.8 for well development procedures). If gravelly or hard material is encountered which prevents advancing the auger to the desired depth, augering should be halted and either driven casing or hydraulic rotary methods should be attempted. If the depth to the bedrock/soil interface and bedrock lithology must be determined, then a 5-foot confirmatory core run should be conducted (see Section 5.2.9).

At the option of the Field Operations Leader (in communication with the Project Manager), when resistant materials prevent the advancement of the auger, a new boring can be attempted. The original boring must be properly backfilled and the new boring started a short distance away at a location determined by the site geologist. If multiple water bearing strata were encountered, the original boring must be grouted. In some formations, it may be prudent to also grout borings which penetrate only the water table aquifer, since loose soil backfill in the boring may still provide a preferred pathway for surface liquids to reach the water table.

### 5.2.2 Continuous-Flight Solid-Stem Auger Drilling

This drilling method is similar to hollow-stem augering. Practical application of this method is severely restricted compared to use of hollow-stem augers. Split-barrel (split-spoon) sampling cannot be performed without pulling the augers out, which may allow the hole to collapse. The continuous-flight solid-stem auger drilling method is therefore very time consuming and is not cost effective. Also, augers would have to be withdrawn before installing a monitoring well, which again, may allow the hole to collapse. Furthermore, geologic logging by examining the soils brought to the surface is unreliable, and depth to water may be difficult to determine while drilling.

There would be very few situations where use of a solid-stem auger would be preferable to other drilling methods. The only practical applications of this method would be to drill boreholes for well installation where no lithologic information is desired and the soils are such that the borehole can be expected to



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remain open after the augers are withdrawn. Alternatively, this technique can be used to find depth to bedrock in an area when no other information is required from drilling.

### 5.2.3 Rotary Drilling

Direct rotary drilling includes air-rotary and fluid-rotary drilling. For air or fluid-rotary drilling, the rotary drill may be advanced to the desired depth by any power-operated drilling machine having sufficient torque and ram range to rotate and force the bit to the desired depth. The drilling machine must, however, be equipped with any accessory equipment needed to perform required sampling, or coring. Prior to sampling, any settled drill cuttings in the borehole must be removed.

Air-rotary drilling is a method of drilling where the drill rig simultaneously turns and exerts a downward pressure on the drilling rods and bit while circulating compressed air down the inside of the drill rods, around the bit, and out the annulus of the borehole. Air circulation serves to both cool the bit and remove the cuttings from the borehole. Advantages of this method include:

- The drilling rate is high (even in rock).
- The cost per foot of drilling is relatively low.
- Air-rotary rigs are common in most areas.
- No drilling fluid is required (except when water is injected to keep down dust).
- The borehole diameter is large, to allow room for proper well installation procedures.

Disadvantages to using this method include:

- Formations must be logged from the cuttings that are blown to the surface and thus the depths of materials logged are approximate.
- Air blown into the formation during drilling may "bind" the formation and impede well development and natural groundwater flow.
- In-situ samples cannot be taken, unless the hole is cased.
- Casing must generally be used in unconsolidated materials.
- Air-rotary drill rigs are large and heavy.

A variation of the typical air-rotary drill bit is a down hole hammer which hammers the drill bit down as it drills. This makes drilling in hard rock faster. Air-rotary drills can also be adapted to use for rock coring although they are generally slower than other types of core drills. A major application of the air-rotary drilling method would be to drill holes in rock for well installation.

Fluid-Rotary drilling operates in a similar manner to air-rotary drilling except that a drilling fluid ("mud") or clean water is used in place of air to cool the drill bit and remove cuttings. There are a variety of fluids that can be used with this drilling method, including bentonite slurry and synthetic slurries. If a drilling fluid other than water/cuttings is used, it must be a natural clay (i.e., bentonite) and a "background" sample of the fluid should be taken for analysis of possible organic or inorganic contaminants.



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Advantages to the fluid-rotary drilling method include:

- The ability to drill in many types of formations.
- Relatively quick and inexpensive.
- Split-barrel (split-spoon) or thin-wall (Shelby) tube samples can be obtained without removing drill rods if the appropriate size drill rods and bits (i.e., fish-tail or drag bit) are used.
- In some borings temporary casing may not be needed as the drilling fluids may keep the borehole open.
- Drill rigs are readily available in most areas.

Disadvantages to this method include:

- Formation logging is not as accurate as with hollow-stem auger method if split-barrel (split-spoon) samples are not taken (i.e., the depths of materials logged from cuttings delivered to the surface are approximate).
- Drilling fluids reduce permeability of the formation adjacent to the boring to some degree, and require more extensive well development than "dry" techniques (augering, air-rotary).
- No information on depth to water is obtainable while drilling.
- Fluids are needed for drilling, and there is some question about the effects of the drilling fluids on subsequent water samples obtained. For this reason as well, extensive well development may be required.
- In very porous materials (i.e., rubble fill, boulders, coarse gravel) drilling fluids may be continuously lost into the formation. This requires either constant replenishment of the drilling fluid, or the use of casing through this formation.
- Drill rigs are large and heavy, and must be supported with supplied water.
- Groundwater samples can be potentially diluted with drilling fluid.

The procedures for performing direct rotary soil investigations and sampling shall conform with the applicable ASTM standards: D2113-83, D1587-83, and D1586-84.

Soil samples shall be taken as specified by project plan documents, or more frequently, if requested by the project geologist. Any required sampling shall be performed by rotation, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool.

When field conditions prevent the advancement of the hole to the desired depth, a new boring may be drilled at the request of the Field Operations Leader. The original boring shall be backfilled using methods and materials appropriate for the given site and a new boring started a short distance away at a location determined by the project geologist.



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#### 5.2.4 Rotosonic Drilling

The Rotosonic drilling method employs a high frequency vibrational and low speed rotational motion coupled with down pressure to advance the cutting edge of a drill string. This produces a uniform borehole while providing a continuous, undisturbed core sample of both unconsolidated and most bedrock formations. Rotosonic drilling advances a 4-inch diameter to 12-inch diameter core barrel for sampling and can advance up to a 12-inch diameter outer casing for the construction of standard and telescoped monitoring wells. During drilling, the core barrel is advanced ahead of the outer barrel in increments as determined by the site geologist and depending upon type of material, degree of subsurface contamination and sampling objectives.

The outer casing can be advanced at the same time as the inner drill string and core barrel, or advanced down over the inner drill rods and core barrel, or after the core barrel has moved ahead to collect the undisturbed sample and has been pulled out of the borehole. The outer casing can be advanced dry in most cases, or can be advanced with water or air depending upon the formations being drilled, the depth and diameter of the hole, or requirements of the project.

Advantages of this method include:

- Sampling and well installation are faster as compared to other drilling methods.
- Continuous sampling, with larger sample volume as compared to split-spoon sampling.
- The ability to drill through difficult formations such as cobbles or boulders, hard till and bedrock.
- Reduction of IDW by an average of 70 to 80 percent.
- Well installations are quick and controlled by elimination of potential bridging of annular materials during well installation, due to the ability to vibrate the outer casing during removal.

Disadvantages include:

- The cost for Rotosonic drilling as compared to other methods are generally higher. However, the net result can be a significant savings considering reduced IDW and shortened project duration.
- Rotosonic drill rigs are large and need ample room to drill, however, Rotosonic units can be placed on the ground or placed on an ATV.
- There are a limited number of Rotosonic drilling contractors at the present time.

#### 5.2.5 Reverse Circulation Rotary Drilling

The common reverse-circulation rig is a water or mud-rotary rig with a large-diameter drill pipe which circulates the drilling water down the annulus and up the inside of the drill pipe (reverse flow direction from direct mud-rotary). This type of rig is used for the construction of large-capacity production water wells and is not suited for small, water quality sampling wells because of the use of drilling muds and the large-diameter hole which is created. A few special reverse-circulation rotary rigs are made with double-wall drill pipe. The drilling water or air is circulated down the annulus between the drill pipes and up inside the inner pipe.



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Advantages of the latter method include:

- The formation water is not contaminated by the drilling water.
- Formation samples can be obtained, from known depths.
- When drilling with air, immediate information is available regarding the water-bearing properties of formations penetrated.
- Collapsing of the hole in unconsolidated formations is not as great a problem as when drilling with the normal air-rotary rig.

Disadvantages include:

- Double-wall, reverse-circulation drill rigs are very rare and expensive to operate.
- Placing cement grout around the outside of the well casing above a well screen often is difficult, especially when the screen and casing are placed down through the inner drill pipe before the drill pipe is pulled out.

#### **5.2.6 Drill-through Casing Driver**

The driven-casing method consists of alternately driving casing (fitted with a sharp, hardened casing shoe) into the ground using a hammer lifted and dropped by the drill rig (or an air-hammer) and cleaning out the casing using a rotary chopping bit and air or water to flush out the materials. The casing is driven down in stages (usually 5 feet per stage); a continuous record is kept of the blows per foot in driving the casing (see SOP GH-1.5). The casing is normally advanced by a 300-pound hammer falling freely through a height of 30 inches. Simultaneous washing and driving of the casing is not recommended. If this procedure is used, the elevations within which wash water is used and in which the casing is driven must be clearly recorded.

The driven casing method is used in unconsolidated formations only. When the boring is to be used for later well installation, the driven casing used should be at least 4 inches larger in diameter than the well casing to be installed. Advantages to this method of drilling include:

- Split-barrel (split-spoon) sampling can be conducted while drilling.
- Well installation is easily accomplished.
- Drill rigs used are relatively small and mobile.
- The use of casing minimizes flow into the hole from upper water-bearing layers; therefore, multiple aquifers can be penetrated and sampled for rough field determinations of some water quality parameters.

Some of the disadvantages include:

- This method can only be used in unconsolidated formations.
- The method is slower than other methods (average drilling progress is 30 to 50 feet per day).



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- Maximum depth of the borehole varies with the size of the drill rig and casing diameter used, and the nature of the formations drilled.
- The cost per hour or per foot of drilling may be substantially higher than other drilling methods.
- It is difficult and time consuming to pull back the casing if it has been driven very deep (deeper than 50 feet in many formations).

#### 5.2.7 Cable Tool Drilling

A cable tool rig uses a heavy, solid-steel, chisel-type drill bit ("tool") suspended on a steel cable, which when raised and dropped, chisels or pounds a hole through the soils and rock. Drilling progress may be expedited by the use of "slip-jars" which serve as a cable-activated down hole percussion device to hammer the bit ahead.

When drilling through the unsaturated zone, some water must be added to the hole. The cuttings are suspended in the water and then bailed out periodically. Below the water table, after sufficient ground water enters the borehole to replace the water removed by bailing, no further water needs to be added.

When soft caving formations are encountered, it is usually necessary to drive casing as the hole is advanced to prevent collapse of the hole. Often the drilling can be only a few feet below the bottom of the casing. Because the drill bit is lowered through the casing, the hole created by the bit is smaller than the casing. Therefore, the casing (with a sharp, hardened casing shoe on the bottom) must be driven into the hole (see Section 5.2.5 of this guideline).

Advantages of the cable-tool method include the following:

- Information regarding water-bearing zones is readily available during the drilling. Even relative permeabilities and rough water quality data from different zones penetrated can be obtained by skilled operators.
- The cable-tool rig can operate satisfactorily in all formations, but is best suited for caving, boulder, cable or coarse gravel type formations (e.g., glacial till) or formations with large cavities above the water table (such as limestones).
- When casing is used, the casing seals formation water out of the hole, preventing down hole contamination and allowing sampling of deeper aquifers for field-measurable water quality parameters.
- Split-barrel (split-spoon) or thin-wall (Shelby) tube samples can be collected through the casing.

Disadvantages include:

- Drilling is slow compared with rotary rigs.
- The necessity of driving the casing in unconsolidated formations requires that the casing be pulled back if exposure of selected water-bearing zones is desired. This process complicates the well completion process and often increases costs. There is also a chance that the casing may become stuck in the hole.



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- The relatively large diameters required (minimum of 4-inch casing) plus the cost of steel casing result in higher costs compared to rotary drilling methods where casing is not required (e.g., such use of a hollow-stem auger).
- Cable-tool rigs have largely been replaced by rotary rigs. In some parts of the U.S., availability may be difficult.

#### 5.2.8 Jet Drilling (Washing)

Jet drilling, which should be used only for piezometer or vadose zone sampler installation, consists of pumping water or drilling mud down through a small diameter (1/2- to 2-inch) standard pipe (steel or PVC). The pipe may be fitted with a chisel bit or a special jetting screen. Formation materials dislodged by the bit and jetting action of the water are brought to the surface through the annulus around the pipe. As the pipe is jetted deeper, additional lengths of pipe may be added at the surface.

Jet percussion is a variation of the jetting method, in which the casing is driven with a drive weight. Normally, this method is used to place 2-inch-diameter casing in shallow, unconsolidated sand formations, but this method has also been used to install 3- to 4-inch-diameter casings to a depth of 200 feet.

Jetting is acceptable in very soft formations, usually for shallow sampling, and when introduction of drilling water to the formation is acceptable. Such conditions would occur during rough stratigraphic investigation or installation of piezometers for water level measurement. Advantages of this method include:

- Jetting is fast and inexpensive.
- Because of the small amount of equipment required, jetting can be accomplished in locations where access by a normal drilling rig would be very difficult. For example, it would be possible to jet down a well point in the center of a lagoon at a fraction of the cost of using a drill rig.
- Jetting numerous well points just into a shallow water table is an inexpensive method for determining the water table contours, hence flow direction.

Disadvantages include the following:

- A large amount of foreign water or drilling mud is introduced above and into the formation to be sampled.
- Jetting is usually done in very soft formations which are subject to caving. Because of this caving, it is often not possible to place a grout seal above the screen to assure that water in the well is only from the screened interval.
- The diameter of the casing is usually limited to 2 inches; therefore, samples must be obtained by methods applicable to small diameter casings.
- Jetting is only possible in very soft formations that do not contain boulders or coarse gravel, and the depth limitation is shallow (about 30 feet without jet percussion equipment).
- Large quantities of water are often needed.



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### 5.2.9 Drilling with a Hand Auger

This method is applicable wherever the formation, total depth of sampling, and the site and groundwater conditions are such as to allow hand auger drilling. Hand augering can also be considered at locations where drill rig access is not possible. All hand auger borings will be performed according to ASTM D1452-80.

Samples should be taken continuously unless otherwise specified by the project plan documents. Any required sampling is performed by rotation, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool. Typical equipment used for sampling and advancing shallow "hand auger" holes are Iwan samplers (which are rotated) or post hole diggers (which are operated like tongs). These techniques are slow but effective where larger pieces of equipment do not have access, and where very shallow holes are desired (less than 15 feet). Surficial soils must be composed of relatively soft and non-cemented formations to allow penetration by the auger.

### 5.2.10 Rock Drilling and Coring

When soil borings cannot be continued using augers or rotary methods due to the hardness of the soil or when rock or large boulders are encountered, drilling and sampling can be performed using a diamond bit corer in accordance with ASTM D2113.

Drilling is done by rotating and applying downward pressure to the drill rods and drill bit. The drill bit is a circular, hollow, diamond-studded bit attached to the outer core barrel in a double-tube core barrel. The use of single-tube core barrels is not recommended, as the rotation of the barrel erodes the sample and limits its use for detailed geological evaluation. Water or air is circulated down through the drill rods and annular space between the core barrel tubes to cool the bit and remove the cuttings. The bit cuts a core out of the rock which rises into an inner barrel mounted inside the outer barrel. The inner core barrel and rock core are removed by lowering a wire line with a coupling into the drill rods, latching onto the inner barrel and withdrawing the inner barrel. A less efficient variation of this method utilizes a core barrel that cannot be removed without pulling all of the drill rods. This variation is practical only if less than 50 feet of core is required.

Core borings are made through the casing used for the soil borings. The casing must be driven and sealed into the rock formation to prevent seepage from the overburden into the hole to be cored (see Section 5.3 of this guideline). A double-tube core barrel with a diamond bit and reaming shell or equivalent should be used to recover rock cores of a size specified in the project plans. The most common core barrel diameters are listed in Attachment A.

Soft or decomposed rock should be sampled with a driven split-barrel whenever possible or cored with a Denison or Pitcher sampler.

When coring rock, including shale and claystone, the speed of the drill and the drilling pressure, amount and pressure of water, and length of run can be varied to give the maximum recovery from the rock being drilled. Should any rock formation be so soft or broken that the pieces continually fall into the hole causing unsatisfactory coring, the hole should be reamed and a flush-joint casing installed to a point below the broken formation. The size of the flush-joint casing must permit securing the core size specified. When soft or broken rock is anticipated, the length of core runs should be reduced to less than 5 feet to avoid core loss and minimize core disturbance.



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Advantages of core drilling include:

- Undisturbed rock cores can be recovered for examination and/or testing.
- In formations in which the cored hole will remain open without casing, water from the rock fractures may be recovered from the well without the installation of a well screen and gravel pack.
- Formation logging is extremely accurate.
- Drill rigs are relatively small and mobile.

Disadvantages include:

- Water or air is needed for drilling.
- Coring is slower than rotary drilling (and more expensive).
- Depth to water cannot accurately be determined if water is used for drilling.
- The size of the borehole is limited.

This drilling method is useful if accurate determinations of rock lithology are desired or if open wells are to be installed into bedrock. To install larger diameter wells in coreholes, the hole must be reamed out to the proper size after boring, using air or mud rotary drilling methods.

#### 5.2.11 Drilling & Support Vehicles

In addition to the drilling method required to accomplish the objectives of the field program, the type of vehicle carrying the drill rig and/or support equipment and its suitability for the site terrain, will often be an additional deciding factor in planning the drilling program. The types of vehicles available are extensive, and depend upon the particular drilling subcontractor's fleet. Most large drilling subcontractors will have a wide variety of vehicle and drill types suited for most drilling assignments in their particular region, while smaller drilling subcontractors will usually have a fleet of much more limited diversity. The weight, size, and means of locomotion (tires, tracks, etc.) of the drill rig must be selected to be compatible with the site terrain to assure adequate mobility between borehole locations. Such considerations also apply to necessary support vehicles used to transport water and/or drilling materials to the drill rigs at the borehole locations. When the drill rigs or support vehicles do not have adequate mobility to easily traverse the site, provisions must be made for assisting equipment, such as bulldozers, winches, timber planking, etc., to maintain adequate progress during the drilling program.

Some of the typical vehicles which are usually available for drill rigs and support equipment are:

- Totally portable drilling/sampling equipment, where all necessary components (tripods, samplers, hammers, catheads, etc.) may be hand carried to the borehole site. Drilling/sampling methods used with such equipment include:
  - Hand augers and lightweight motorized augers.
  - Retractable plug samplers—driven by hand (hammer).



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- Motorized cathead - a lightweight aluminum tripod with a small gas-engine cathead mounted on one leg, used to install small-diameter cased borings. This rig is sometimes called a "monkey on a stick."
- Skid-mounted drilling equipment containing a rotary drill or engine-driven cathead (to lift hammers and drill string), a pump, and a dismounted tripod. The skid is pushed, dragged, or winched (using the cathead drum) between boring locations.
- Small truck-mounted drilling equipment using a jeep, stake body or other light truck (4 to 6 wheels), upon which are mounted the drill and/or a cathead, a pump, and a tripod or small drilling derrick. On some rigs, the drill and/or a cathead are driven by a power take-off from the truck, instead of by a separate engine.
- Track-mounted drilling equipment is similar to truck-mounted rigs, except that the vehicle used has wide bulldozer tracks for traversing soft ground. Sometimes a continuous-track "all terrain vehicle" is also modified for this purpose. Some types of tracked drill rigs are called "bombardier" or "weasel" rigs.
- Heavy truck-mounted drilling equipment is mounted on tandem or dual tandem trucks to transport the drill, derrick, winches, and pumps or compressors. The drill may be provided with a separate engine or may use a power take-off from the truck engine. Large augers, hydraulic rotary and reverse circulation rotary drilling equipment are usually mounted on such heavy duty trucks. For soft-ground sites, the drilling equipment is sometimes mounted on and off the road vehicle having low pressure, very wide diameter tires and capable of floating; these vehicles are called "swamp buggy" rigs.
- Marine drilling equipment is mounted on various floating equipment for drilling borings in lakes, estuaries and other bodies of water. The floating equipment varies, and is often manufactured or customized by the drilling subcontractor to suit specific drilling requirements. Typically, the range of flotation vehicles include:
  - Barrel-float rigs - a drill rig mounted on a timber platform buoyed by empty 55-gallon drums or similar flotation units.
  - Barge-mounted drill rigs.
  - Jack-up platforms - drilling equipment mounted on a floating platform having retractable legs to support the unit on the sea or lake bed when the platform is jacked up out of the water.
  - Drill ships - for deep ocean drilling.

In addition to the mobility for the drilling equipment, similar consideration must be given for equipment to support the drilling operations. Such vehicles or floating equipment are needed to transport drill water, drilling supplies and equipment, samples, drilling personnel, etc. to and/or from various boring locations.

#### 5.2.12 Equipment Sizes

In planning subsurface exploration programs, care must be taken in specifying the various drilling components, so that they will fit properly in the boring or well.



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For drilling open boreholes using rotary drilling equipment, tri-cone drill bits are employed with air, water or drilling mud to remove cuttings and cool the bit. Tri-cone bits are slightly smaller than the holes they drill (i.e., 5-7/8-inch or 7-7/8-inch bits will nominally drill 6-inch and 8-inch holes, respectively).

For obtaining split-barrel samples of a formation, samplers are commonly manufactured in sizes ranging from 2 inches to 3-1/2 inches in outside diameter. However, the most commonly used size is the 2-inch O.D., 1-3/8-inch I.D. split-barrel sampler. When this sampler is used and driven by a 140-pound ( $\pm$  2-pound) hammer dropping 30 inches ( $\pm$  1 inch), the procedure is called a Standard Penetration Test, and the blows per foot required to advance the sampler into the formation can be correlated to the formation's density or strength.

In planning the drilling of boreholes using hollow-stem augers or casing, in which thin-wall tube samples or diamond core drilling will be performed, refer to the various sizes and clearances provided in Attachment A of this guideline. Sizes selected must be stated in the project plan documents.

#### 5.2.13 Estimated Drilling Progress

To estimate the anticipated rates of drilling progress for a site, the following must be considered:

- The speed of the drilling method employed.
- Applicable site conditions (e.g., terrain, mobility between borings, difficult drilling conditions in bouldery soils, rubble fill or broken rock, etc.).
- Project-imposed restrictions (e.g., drilling while wearing personal protective equipment, decontamination of drilling equipment, etc.).

Based on recent experience in drilling average soil conditions (no boulders) and taking samples at 5-foot intervals, for moderate depth (30 feet to 50 feet) boreholes (not including installation or development of wells), the following daily rates of total drilling progress may be anticipated for the following drilling methods:

Drilling Method	Average Daily Progress (linear feet)
Hollow-stem augers	75'
Solid-stem augers	50'
Mud-Rotary Drilling	100' (cuttings samples)
Rotosonic Drilling	100'-160' (continuous core)
Reverse-Circulation Rotary	100' (cuttings samples)
Skid-Rig with driven casing	30'
Rotary with driven casing	50'
Cable Tool	30'
Hand Auger	Varies
Continuous Rock Coring	50'



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### 5.3 Prevention of Cross-Contamination

A telescoping or multiple casing technique minimizes the potential for the migration of contaminated groundwater to lower strata below a confining layer. The telescoping technique consists of drilling to a confining layer utilizing a spun casing method with a diamond cutting or augering shoe (a method similar to the rock coring method described in Section 5.2.10, except that larger casing is used) or by using a driven-casing method (see Section 5.2.6 of this guideline) and installing a specified diameter steel well casing. The operation consists of three separate steps. Initially, a drilling casing (usually of 8-inch diameter) is installed followed by installation of the well casing (6-inch-diameter is common for 2-inch wells). This well casing is driven into the confining layer to ensure a tight seal at the bottom of the hole. The well casing is sealed at the bottom with a bentonite-cement slurry. The remaining depth of the boring is drilled utilizing a narrower diameter spun or driven casing technique within the outer well casing. A smaller diameter well casing with an appropriate length of slotted screen on the lower end, is installed to the surface.

Clean sand is placed in the annulus around and to a point of about 2 feet above the screen prior to withdrawal of the drilling casing. The annular space above the screen and to a point 2 feet above the bottom of the outer well casing is sealed with a tremied cement-bentonite slurry which is pressure-grouted or displacement-grouted into the hole. The remaining casing annulus is backfilled with clean material and grouted at the surface, or it is grouted all the way to the surface.

### 5.4 Cleanout of Casing Prior to Sampling

The boring hole must be completely cleaned of disturbed soil, segregated coarse material and clay adhering to the inside walls of the casing. The cleaning must extend to the bottom edge of the casing and, if possible, a short distance further (1 or 2 inches) to bypass disturbed soil resulting from the advancement of the casing. Loss of wash water during cleaning should be recorded.

For disturbed samples both above and below the water table and where introduction of relatively large volumes of wash water is permissible, the cleaning operation is usually performed by washing the material out of the casing with water; however, the cleaning should never be accomplished with a strong, downward-directed jet which will disturb the underlying soil. When clean out has reached the bottom of the casing or slightly below (as specified above), the string of tools should be lifted one foot off the bottom with the water still flowing, until the wash water coming out of the casing is clear of granular soil particles. In formations where the cuttings contain gravel and other larger particles, it is often useful to repeatedly raise and lower the drill rods and wash bit while washing out the hole, to surge these large particles upward out of the hole. As a time saver, the drilling contractor may be permitted to use a split-barrel (split-spoon) sampler with the ball check valve removed as the clean-out tool, provided the material below the spoon is not disturbed and the shoe of the spoon is not damaged. However, because the ball check valve has been removed, in some formations it may be necessary to install a flap valve or spring sample retainer in the split-spoon bit, to prevent the sample from falling out as the sampler is withdrawn from the hole. The use of jet-type chopping bits is discouraged except where large boulders and cobbles or hard-cemented soils are encountered. If water markedly softens the soils above the water table, clean out should be performed dry with an auger.

For undisturbed samples below the water table, or where wash water must be minimized, clean out is usually accomplished with an appropriate diameter clean out auger. This auger has cutting blades at the bottom to carry loose material up into the auger, and up-turned water jets just above the cutting blades to carry the removed soil to the surface. In this manner, there is a minimum of disturbance at the top of the material to be sampled. If any gravel material washes down into the casing and cannot be removed by the clean out auger, a split-barrel sample can be taken to remove it; bailers and



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sandpumps should not be used. For undisturbed samples above the groundwater table, all operations must be performed in a dry manner.

If all of the cuttings created by drilling through the overlying formations are not cleaned from the borehole prior to sampling, some of the problems which may be encountered during sampling include:

- When sampling is attempted through the cuttings remaining in the borehole, all or part of the sampler may become filled with the cuttings. This limits the amount of sample from the underlying formation which can enter and be retained in the sampler, and also raises questions as to the validity of the sample.
- If the cuttings remaining in the borehole contain coarse gravel and/or other large particles, these may block the bit of the sampler and prevent any materials from the underlying formation from entering the sampler when the sampler is advanced.
- In cased borings, should sampling be attempted through cuttings which remain in the lower portion of the casing, these cuttings could cause the sampler to become bound into the casing, such that it becomes very difficult to either advance or retract the sampler.
- When sampler blow counts are used to estimate the density or strength of the formation being sampled, the presence of cuttings in the borehole will usually give erroneously high sample blow counts.

To confirm that all cuttings have been removed from the borehole prior to attempting sampling, it is important that the rig geologist measure the "stickup" of the drill string. This is accomplished by measuring the assembled length of all drill rods and bits or samplers (the drill string) as they are lowered to the bottom of the hole, below some convenient reference point of the drill string, then measuring the height of this reference point above the ground surface. The difference of these measurements is the depth of the drill string (lower end of the bit or sampler) below the ground surface, which must then be compared with the depth of sampling required (installed depth of casing or depth of borehole drilled). If the length of drill string below grade is more than the drilled or casing depth, the borehole has been cleaned too deeply, and this deeper depth of sampling must be recorded on the log. If the length of drill string below grade is less than the drilled or casing depth, the difference represents the thickness of cuttings which remain in the borehole. In most cases, an inch or two of cuttings may be left in the borehole with little or no problem. However, if more than a few inches of cuttings are encountered, the borehole must be recleaned prior to attempting sampling.

## 5.5 Materials of Construction

The effects of monitoring well construction materials on specific chemical analytical parameters are described and/or referenced in SOP GH-2.8. However, there are several materials used during drilling, particularly drilling fluids and lubricants, which must be used with care to avoid compromising the representativeness of soil and ground water samples.

The use of synthetic or organic polymer slurries is not permitted at any location where soil samples for chemical analysis are to be collected. These slurry materials could be used for installation of long-term monitoring wells, but the early time data in time series collection of ground water data may then be suspect. If synthetic or organic polymer muds are proposed for use at a given site, a complete written justification including methods and procedures for their use must be provided by the site geologist and approved by the Project Manager. The specific slurry composition and the concentration of suspected contaminants for each site must be known.



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For many drilling operations, potable water is an adequate lubricant for drill stem and drilling tool connections. However, there are instances, such as drilling in tight clayey formations or in loose gravels, when threaded couplings must be lubricated to avoid binding. In these instances, to be determined in the field by the judgment of the site geologist and noted in the site logbook, and only after approval by the Project Manager, a vegetable oil or silicone-based lubricant should be used. Petroleum based greases, etc. will not be permitted. Samples of lubricants used must be provided and analyzed for chemical parameters appropriate to the given site.

## 5.6 Subsurface Soil Samples

Subsurface soil samples are used to characterize subsurface stratigraphy. This characterization can indicate the potential for migration of chemical contaminants in the subsurface. In addition, definition of the actual migration of contaminants can be obtained through chemical analysis of the soil samples. Where the remedial activities may include in-situ treatment or excavation and removal of the contaminated soil, the depth and areal extent of contamination must be known as accurately as possible.

Engineering and physical properties of soil may also be of interest should site construction activities be planned. Soil types, grain size distribution, shear strength, compressibility, permeability, plasticity, unit weight, and moisture content are some of the physical characteristics that may be determined for soil samples.

Penetration tests are also described in this procedure. The tests can be used to estimate various physical and engineering parameters such as relative density, unconfined compressive strength, and consolidation characteristics of soils.

Surface protocols for various soil sampling techniques are discussed in SOP SA-1.3. Continuous-core soil sampling and rock coring are discussed below. The procedures described here are representative of a larger number of possible drilling and sampling techniques. The choice of techniques is based on a large number of variables such as cost, local geology, etc. The final choice of methods must be made with the assistance of drilling subcontractors familiar with the local geologic conditions. Alternative techniques must be based upon the underlying principles of quality assurance implicit in the following procedures.

The CME continuous sample tube system provides a method of sampling soil continuously during hollow-stem augering. The 5-foot sample barrel fits within the lead auger of a hollow-auger column. The sampling system can be used with a wide range of I.D. hollow-stem augers (from 3-1/4-inch to 8-1/4-inch I.D.). This method has been used to sample many different materials such as glacial drift, hard clays and shales, mine tailings, etc. This method is particularly used when SPT samples are not required and a large volume of material is needed. Also, this method is useful when a visual description of the subsurface lithology is required. Rotasonic drilling methods also provide a continuous soil sample.

## 5.7 Rock Sampling (Coring) (ASTM D2113-83)

Rock coring enables a detailed assessment of borehole conditions to be made, showing precisely all lithologic changes and characteristics. Because coring is an expensive drilling method, it is commonly used for shallow studies of 500 feet or less, or for specific intervals in the drill hole that require detailed logging and/or analyzing. Rock coring can, however, proceed for thousands of feet continuously, depending on the size of the drill rig, and yields better quality data than air-rotary drilling, although at a substantially reduced drilling rate. Rate of drilling varies widely, depending on the characteristics of lithologies encountered, drilling methods, depth of drilling, and condition of drilling equipment. Average



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output in a 10-hour day ranges from 40 to over 200 feet. Down hole geophysical logging or television camera monitoring is sometimes used to complement the data generated by coring.

Borehole diameter can be drilled to various sizes, depending on the information needed. Standard sizes of core barrels (showing core diameter) and casing are shown in Figure 1.

Core drilling is used when formations are too hard to be sampled by soil sampling methods and a continuous solid sample is desired. Usually, soil samples are used for overburden, and coring begins in sound bedrock. Casing is set into bedrock before coring begins to prevent loose material from entering the borehole, to prevent loss of drilling fluid, and to prevent cross-contamination of aquifers.

Drilling through bedrock is initiated by using a diamond-tipped core bit threaded to a drill rod (outer core barrel) with a rate of drilling determined by the downward pressure, rotation speed of drill rods, drilling fluid pressure in the borehole, and the characteristics of the rock (mineralogy, cementation, weathering).

#### 5.7.1 Diamond Core Drilling

A penetration of typically less than 6 inches per 50 blows using a 140-lb. hammer dropping 30 inches with a 2-inch split-barrel sampler shall be considered an indication that soil sampling methods may not be applicable and that coring may be necessary to obtain samples.

When formations are encountered that are too hard to be sampled by soil sampling methods, the following diamond core drilling procedure may be used:

- Firmly seat a casing into the bedrock or the hard material to prevent loose materials from entering the hole and to prevent the loss of drilling fluid return. Level the surface of the rock or hard material when necessary by the use of a fishtail or other bits. If the drill hole can be retained open without the casing and if cross-contamination of aquifers in the unconsolidated materials is unlikely, leveling may be omitted.
- Begin the core drilling using a double-tube swivel-core barrel of the desired size. After drilling no more than 10 feet (3 m), remove the core barrel from the hole and take out the core. If the core blocks the flow of the drilling fluid during drilling, remove the core barrel immediately. In soft materials, a large starting size may be specified for the coring tools; where local experience indicates satisfactory core recovery or where hard, sound materials are anticipated, a smaller size or the single-tube type may be specified and longer runs may be drilled. NX/NW size coring equipment is the most commonly used size.
- When soft materials are encountered that produce less than 50 percent recovery, stop the core drilling. If soil samples are desired, secure such samples in accordance with the procedures described in ASTM Method D 1586 (Split-barrel Sampling) or in Method D 1587 (Thin-Walled Tube Sampling); sample soils per SOP SA-1.3. Resume diamond core drilling when refusal materials are again encountered.
- Since rock structures and the occurrence of seams, fissures, cavities, and broken areas are among the most important items to be detected and described, take special care to obtain and record these features. If such broken zones or cavities prevent further advance of the boring, one of the following three steps shall be taken: (1) cement the hole; (2) ream and case; or (3) case and advance with the next smaller size core barrel, as conditions warrant.



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FIGURE 1

STANDARD SIZES OF CORE BARRELS AND CASING

Coring Bit Size	Nominal*		Set Size*	
	O.D.	I.D.	O.D.	I.D.
RWT	1 5/32	3/4	1.160	0.735
EWT	1 1/2	29/32	1.470	0.905
EX, EXL, EWG, EWM	1 1/2	13/16	1.470	0.845
AWT	1 7/8	1 9/32	1.875	1.281
AX, AXL, AWG, AWM	1 7/8	1 3/16	1.875	1.185
BWT	2 3/8	1 3/4	2.345	1.750
BX, BXL, BWG, BWM	2 3/8	1 5/8	2.345	1.655
NWT	3	2 5/16	2.965	2.313
NX, NXL, NWG, NWM	3	2 1/8	2.965	2.155
HWT	3 29/32	3 3/16	3.889	3.187
HWG	3 29/32	3	3.889	3.000
2 3/4 x 3 7/8	3 7/8	2 3/4	3.840	2.690
4 x 5 1/2	5 1/2	4	5.435	3.970
6 x 7 3/4	7 3/4	6	7.655	5.970
AX Wire line ____/____/	1 7/8	1	1.875	1.000
BX Wire line ____/____/	2 3/8	1 7/16	2.345	1.437
NX Wire line ____/____/	3	1 15/16	2.965	1.937

\* All dimensions are in inches; to convert to millimeters, multiply by 25.4.

\_\_\_\_/\_\_\_\_/ Wire line dimensions and designations may vary according to manufacturer.



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**FIGURE 1**  
**STANDARD SIZES OF CORE BARRELS AND CASING**  
**PAGE TWO**

Size Designations		Casing O.D., Inches	Casing Coupling		Casing bit O.D., Inches	Core barrel bit O.D., Inches*	Drill rod O.D., Inches	Approximate Core Diameter	
Casing; Casing coupling; Casing bits; Core barrel bits	Rod; rod couplings		O.D., Inches	I.D., Inches				Normal, Inches	Thinwall, Inches
RX	RW	1.437	1.437	1.188	1.485	1.160	1.094	---	0.735
EX	E	1.812	1.812	1.500	1.875	1.470	1.313	0.845	0.905
AX	A	2.250	2.250	1.906	2.345	1.875	1.625	1.185	1.281
BX	B	2.875	2.875	2.375	2.965	2.345	1.906	1.655	1.750
NX	N	3.500	3.500	3.000	3.615	2.965	2.375	2.155	2.313
HX	HW	4.500	4.500	3.938	4.625	3.890	3.500	3.000	3.187
RW	RW	1.437	Flush Joint	No Coupling	1.485	1.160	1.094	---	0.735
EW	EW	1.812			1.875	1.470	1.375	0.845	0.905
AW	AW	2.250			2.345	1.875	1.750	1.185	1.281
BW	BW	2.875			2.965	2.345	2.125	1.655	1.750
NW	NW	3.500			3.615	2.965	2.625	2.155	2.313
HW	HW	4.500			4.625	3.890	3.500	3.000	3.187
PW	---	5.500			5.650	---	---	---	---
SW	---	6.625			6.790	---	---	---	---
UW	---	7.625			7.800	---	---	---	---
ZW	---	8.625			8.810	---	---	---	---
---	AX ___ ___\	---	---	---	---	1.875	1.750	1.000	---
---	BX ___ ___\	---	---	---	---	2.345	2.250	1.437	---
---	NX ___ ___\	---	---	---	---	2.965	2.813	1.937	---

\* All dimensions are in inches; to convert to millimeters, multiply by 254.

\_\_\_|\_\_\_/ Wire line dimensions and designations may vary according to manufacturer.

**NOMINAL DIMENSIONS FOR DRILL CASINGS AND ACCESSORIES.**  
**(DIAMOND CORE DRILL MANUFACTURERS ASSOCIATION). 288-D-2889**



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- In soft, seamy, or otherwise unsound rock, where core recovery may be difficult, M-design core barrels may be used. In hard, sound rock where a high percentage of core recovery is anticipated, the single-tube core barrel may be employed.

#### 5.7.2 Rock Sample Preparation and Documentation

Once the rock coring has been completed and the core recovered, the rock core shall be carefully removed from the barrel, placed in a core tray (previously labeled "top" and "bottom" to avoid confusion), classified, and measured for percentage of recovery as well as the rock quality designation (RQD). Each core shall be described, classified, and logged using a uniform system as presented in SOP GH-1.5. If moisture content will be determined or if it is desirable to prevent drying (e.g., to prevent shrinkage of clay formations) or oxidation of the core, the core shall be wrapped in plastic sleeves immediately after logging. Each plastic sleeve shall be labeled with indelible ink. The boring number, run number, and the footage represented in each sleeve shall be included, as well as designating the top and bottom of the core run.

After sampling, rock cores shall be placed in the sequence of recovery in well-constructed wooden boxes provided by the drilling contractor. Rock cores from two different borings shall not be placed in the same core box unless accepted by the Project Geologist. The core boxes shall be constructed to accommodate at least 20 linear feet of core in rows of approximately 5 feet each and shall be constructed with hinged tops secured with screws, and a latch (usually a hook and eye) to keep the top securely fastened down. Wood partitions shall be placed at the end of each core run and between rows.

The depth from the surface of the boring to the top and bottom of the drill run and run number shall be marked on the wooden partitions with indelible ink. A wooden partition (wooden block) shall be placed at the end of each run with the depth of the bottom of the run written on the block. These blocks will serve to separate successive core runs and indicate depth intervals for each run. The order of placing cores shall be the same in all core boxes. Rock core shall be placed in the box so that, when the box is open, with the inside of the lid facing the observer, the top of the cored interval contained within the box is in the upper left corner of the box, and the bottom of the cored interval is in the lower right corner of the box. The top and bottom of each core obtained and its true depth shall be clearly and permanently marked on each box. The width of each row must be compatible with the core diameter to prevent lateral movement of the core in the box. Similarly, an empty space in a row shall be filled with an appropriate filler material or spacers to prevent longitudinal movement of the core in the box.

The inside and outside of the core-box lid shall be marked by indelible ink to show all pertinent data on the box's contents. At a minimum, the following information shall be included:

- Project name.
- Project number.
- Boring number.
- Run numbers.
- Footage (depths).
- Recovery.
- RQD (%).
- Box number and total number of boxes for that boring (Example: Box 5 of 7).

For easy retrieval when core boxes are stacked, the sides and ends of the box shall also be labeled and include project number, boring number, top and bottom depths of core and box number.



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Prior to final closing of the core box, a photograph of the recovered core and the labeling on the inside cover shall be taken. If moisture content is not critical, the core shall be wetted and wiped clean for the photograph. (This will help to show true colors and bedding features in the cores).

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## ATTACHMENT A

### DRILLING EQUIPMENT SIZES

Drilling Component	Designation or Hole Size (Inches)	O.D. (Inches)	I.D. (Inches)	Coupling I.D. (Inches)
Hollow-stem augers (Ref. 7)	6 1/4	5	2 1/4	
	6 3/4	5 3/4	2 3/4	---
	7 1/4	6 1/4	3 1/4	---
	13 1/4	12	6	---
Thin Wall Tube Samplers (Ref. 7)	---	2	1 7/8	---
	---	2 1/2	2 3/8	---
	---	3	2 7/8	---
	---	3 1/2	3 3/8	---
	---	4 1/2	4 3/8	---
	---	5	4 3/4	---
Drill Rods (Ref. 7)	RW	1 3/32	23/32	13/32
	EW	1 3/8	15/16	7/16
	AW	1 3/4	1 1/4	5/8
	BW	2 1/8	1 3/4	3/4
	NW	2 5/8	2 1/4	1 3/8
	HW	3 1/2	3 1/16	2 3/8
	E	1 5/16	7/8	7/16
	A	1 5/8	1 1/8	9/16
	B	1 7/8	1 1/4	5/8
	N	2 3/8	2	1
				Wall Thickness (Inches)
Driven External Coupled Extra Strong Steel* Casing (Ref. 8)	2 1/2	2.875	2.323	0.276
	3	3.5	2.9	0.300
	3 1/2	4.0	3.364	0.318
	4	4.5	3.826	0.337
	5	5.63	4.813	0.375
	6	6.625	5.761	0.432
	8	8.625	7.625	0.500
	10	10.750	9.750	0.500
	12	12.750	11.750	0.500

\* Add twice the casing wall thickness to casing O.D. to obtain the approximate O.D. of the external pipe couplings.



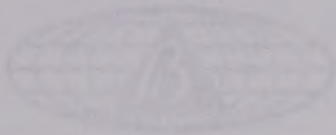
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**ATTACHMENT A  
DRILLING EQUIPMENT SIZES  
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Drilling Component	Designation or Hole Size (Inches)	O.D. (Inches)	I.D. (Inches)	Coupling I.D. (Inches)
Flush Coupled Casing (Ref. 7)	RX	1 7/16	1 3/16	1 3/16
	EX	1 13/16	1 5/8	1 1/2
	AX	2 1/4	2	1 29/32
	BX	2 7/8	2 9/16	2 3/8
	NX	3 1/2	3 3/16	3
	HX	4 1/2	4 1/8	3 15/16
Flush Joint Casing (Ref. 7)	RW	1 7/16	1 3/16	
	EW	1 13/16	1 1/2	
	AW	2 1/4	1 29/32	
	BW	2 7/8	2 3/8	
	NW	3 1/2	3	
	HW	4 1/2	4	
	PW	5 1/2	5	
	SW	6 5/8	6	
	UW	7 5/8	7	
	ZW	8 5/8	8	
Diamond Core Barrels (Ref. 7)	EWM	1 1/2	7/8**	
	AWM	1 7/8	1 1/8**	
	BWM	2 3/8	1 5/8**	
	NWM	3	2 1/8	
	HWG	3 7/8	3	
	2 3/4 x 3 7/8	3 7/8	2 11/16	
	4 x 5 1/2	5 1/2	3 15/16	
	6 x 7 3/4	7 3/4	5 15/16	
	AQ (wireline)	1 57/64	1 1/16**	
	BQ (wireline)	2 23/64	1 7/16**	
	NQ (wireline)	2 63/64	1 7/8	
	HQ (wireline)	3 25/32	2 1/2	

\*\* Because of the fragile nature of the core and the difficulty to identify rock details, use of small-diameter core (1 3/8") is not recommended.





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## SCIENCE AND SAMPLE LOGGING

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# SOIL AND ROCK DRILLING METHODS

Chapter 2

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Drilling Conditions	Recommended Rod Size (inches)	1-1/2 inches	2 inches	Coasting 1-3 inches
High Capacity - Casing (ft 1)	10	1 1/2	1 3/4	1 3/4
	20	1 1/2	1 3/4	1 1/2
	30	2 1/4	2	1 3/4
	40	2 1/2	2 1/4	2 x 3
	50	3 1/2	3 1/4	3
	60	4 1/2	4 1/4	3 1/4
Low Capacity - Casing (ft 2)	80	1 1/2	1 3/4	
	100	1 1/2	1 1/2	
	120	2 1/4	1 3/4	
	140	2 1/2	2	
	160	3 1/2	2	
	180	3 1/2	4	
	200	3 1/2	5	
	220	3 1/2	6	
	240	3 1/2	7	
	260	3 1/2	8	
Standard Casing (ft 3)	280	3 1/2	1 3/4	
	300	3 1/2	1 3/4	
	320	3 1/2	1 3/4	
	340	3	1 1/2	
	360	3 1/2	3	
	380	3 1/2	2 1/4	
	400	3 1/2	2 1/4	
	420	3 1/2	2 1/4	
	440	3 1/2	2 1/4	
	460	3 1/2	2 1/4	
	480	3 1/2	2 1/4	
	500	3 1/2	2 1/4	

\*\* Because of the large range of the data and the difficulty in making any direct comparison of the data, the data is not recommended.





BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

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Subject  
BOREHOLE AND SAMPLE LOGGING

Approved  
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## 1.0 PURPOSE

The purpose of this document is to establish standard procedures and technical guidance on borehole and sample logging.

## 2.0 SCOPE

These procedures provide descriptions of the standard techniques for borehole and sample logging. These techniques shall be used for each boring logged to provide consistent descriptions of subsurface lithology. While experience is the only method to develop confidence and accuracy in the description of soil and rock, the field geologist/engineer can do a good job of classification by careful, thoughtful observation and by being consistent throughout the classification procedure.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

Site Geologist. Responsible for supervising all boring activities and assuring that each borehole is completely logged. If more than one rig is being used on site, the Site Geologist must make sure that each field geologist is properly trained in logging procedures. A brief review or training session may be necessary prior to the start up of the field program and/or upon completion of the first boring.

## 5.0 PROCEDURES

The classification of soil and rocks is one of the most important jobs of the field geologist/engineer. To maintain a consistent flow of information, it is imperative that the field geologist/engineer understand and accurately use the field classification system described in this SOP. This identification is based on visual examination and manual tests.

### 5.1 Materials Needed

When logging soil and rock samples, the geologist or engineer may be equipped with the following:

- Rock hammer
- Knife
- Camera
- Dilute hydrochloric acid (HCl)
- Ruler (marked in tenths and hundredths of feet)
- Hand Lens

### 5.2 Classification of Soils

All data shall be written directly on the boring log (Figure 1) or in a field notebook if more space is needed. Details on filling out the boring log are discussed in Section 5.5.

#### 5.2.1 USCS Classification

Soils are to be classified according to the Unified Soil Classification System (USCS). This method of classification is detailed in Figure 1 (Continued).







FIGURE 1 (CONTINUED)

## SOIL TERMS

UNIFIED SOIL CLASSIFICATION (USCS)											
COARSE-GRAINED SOILS More Than Half of Material is LARGER Than No. 200 Sieve Size						FINE-GRAINED SOILS More Than Half of Material is SMALLER Than No. 200 Sieve Size					
FIELD IDENTIFICATION PROCEDURES (Excluding Particles Larger Than 3 Inches and Basing Fractions on Estimated Weights)			GROUP SYMBOL	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES (Excluding Particles Larger Than 3 Inches and Basing Fractions on Estimated Weights)				GROUP SYMBOL	TYPICAL NAMES	
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size						
						DAY STRENGTH (Crushing Characteristics)	DILATANCY (Reaction to Shaking)	TOUGHNESS (Consistency Near Plastic Limit)			
GRAVELS (50%+) > 1/4"	CLEAN GRAVELS (Low % Fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes.	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	SILTS AND CLAYS Liquid Limit <50	None to Slight	Quick to Slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.	
		Predominantly one size or a range of sizes with some intermediate sizes missing.	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.		Medium to High	None to Very Slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	
	GRAVELS W/FINES (High % Fines)	Non-plastic fines (for identification procedures, see ML)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures.		Slight to Medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity.	
		Plastic fines (for identification procedures, see CL)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.	Slight to Medium	Slow to None	Slight to Medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.		
SANDS 50%+) < 1/4"	CLEAN SANDS (Low % Fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes.	SW	Well graded sand, gravelly sands, little or no fines.	SILTS AND CLAYS Liquid Limit >50	High to Very High	None	High	CH	Inorganic clays of high plasticity, fat clays.	
		Predominantly one size or a range of sizes with some intermediate sizes missing.	SP	Poorly graded sands, gravelly sands, little or no fines.		Medium to High	None to Very Slow	Slight to Medium	OH	Organic clays of medium to high plasticity.	
	SANDS W/FINES (High % Fines)	Non-plastic fines (for identification procedures, see MCL)	SM	Silty sands, poorly graded sand-silt mixtures.		HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel and frequently by fibrous texture.			PT	Peat and other organic soils
		Plastic fines (for identification procedures, see CL)	SC	Clayey sands, poorly graded sand-clay mixtures.							

Boundary classifications: Soils possessing characteristics of two groups are designated by combining group symbols. For example, GW-GC, well graded gravel-sand mixture with clay binder. All sieve sizes on this chart are U.S. Standard.

DENSITY OF GRANULAR SOILS	
DESIGNATION	STANDARD PENETRATION RESISTANCE-BLOWS/FOOT
Very Loose	0-4
Loose	5-10
Medium Loose	11-30
Dense	31-50
Very Dense	Over 50

CONSISTENCY OF COHESIVE SOILS			
CONSISTENCY	UNC. COMPRESSIVE STRENGTH (TONS/SQ. FT.)	STANDARD PENETRATION RESISTANCE-BLOWS/FOOT	FIELD IDENTIFICATION METHODS
Very Soft	Less than 0.25	0 to 2	Easily penetrated several inches by fist
Soft	0.25 to 0.50	2 to 4	Easily penetrated several inches by thumb.
Medium Stiff	0.50 to 1.0	4 to 8	Can be penetrated several inches by thumb.
Stiff	1.0 to 2.0	8 to 15	Readily indented by thumb.
Very Stiff	2.0 to 4.0	15 to 30	Readily indented by thumbnail.
Hard	More than 4.0	Over 30	Indented with difficulty by thumbnail.

## ROCK TERMS

ROCK HARDNESS (FROM CORE SAMPLES)			ROCK BROKENNESS		
Descriptive Terms	Screwdriver or Knife Effects	Hammer Effects	Descriptive Terms	Abbreviation	Spacing
Soft	Easily gouged	Crushes when pressed with hammer	Very Broken	(V. Br.)	0-2"
Medium Soft	Can be gouged	Breaks (one blow); crumbly edges	Broken	(Br.)	2"-1'
Medium Hard	Can be scratched	Breaks (one blow); sharp edges	Blocky	(Bl.)	1'-3"
Hard	Cannot be scratched	Breaks conchoidally (several blows); sharp edges	Massive	(M.)	3'-10'

## LEGEND:

## SOIL SAMPLES - TYPES

- B-2" Split-Barrel Sample  
 BT-3" O.D. Undisturbed Sample  
 O - Other Samples, Specify in Remarks

## ROCK SAMPLES - TYPES

- X-MX (Conventional) Core (-2-1/8" O.D.)  
 Q-MQ (Wireline) Core (-1-1/8" O.D.)  
 Z - Other Core Sizes, Specify in Remarks

## WATER LEVELS

- 12/10  
 12-6" Initial Level w/Date & Depth  
 12/10  
 12-6" Stabilized Level w/Date & Depth



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This method of classification identifies soil types on the basis of grain size and cohesiveness.

Fine-grained soils, or fines, are smaller than the No. 200 sieve and are of two types: silt (M) and clay (C). Some classification systems define size ranges for these soil particles, but for field classification purposes, they are identified by their respective behaviors. Organic material (O) is a common component of soil but has no size range; it is recognized by its composition. The careful study of the USCS will aid in developing the competence and consistency necessary for the classification of soils.

Coarse-grained soils shall be divided into rock fragments, sand, or gravel. The terms sand and gravel not only refer to the size of the soil particles but also to their depositional history. To insure accuracy in description, the term rock fragments shall be used to indicate angular granular materials resulting from the breakup of rock. The sharp edges typically observed indicate little or no transport from their source area, and therefore the term provides additional information in reconstructing the depositional environment of the soils encountered. When the term "rock fragments" is used it shall be followed by a size designation such as "(1/4 inch $\Phi$ -1/2 inch $\Phi$ )" or "coarse-sand size" either immediately after the entry or in the remarks column. The USCS classification would not be affected by this variation in terms.

#### 5.2.2 Color

Soil colors shall be described utilizing a single color descriptor preceded, when necessary, by a modifier to denote variations in shade or color mixtures. A soil could therefore be referred to as "gray" or "light gray" or "blue-gray." Since color can be utilized in correlating units between sampling locations, it is important for color descriptions to be consistent from one boring to another.

Colors must be described while the sample is still moist. Soil samples shall be broken or split vertically to describe colors. Samplers tend to smear the sample surface creating color variations between the sample interior and exterior.

The term "mottled" shall be used to indicate soils irregularly marked with spots of different colors. Mottling in soils usually indicates poor aeration and lack of good drainage.

Soil Color Charts shall not be used unless specified by the project manager.

#### 5.2.3 Relative Density and Consistency

To classify the relative density and/or consistency of a soil, the geologist is to first identify the soil type. Granular soils contain predominantly sands and gravels. They are noncohesive (particles do not adhere well when compressed). Finer-grained soils (silts and clays) are cohesive (particles will adhere together when compressed).

The density of noncohesive, granular soils is classified according to standard penetration resistances obtained from split-barrel sampling performed according to the methods detailed in Standard Operating Procedures GH-1.3 and SA-1.3. Those designations are:



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Designation	Standard Penetration Resistance (Blows per Foot)
Very loose	0 to 4
Loose	5 to 10
Medium dense	11 to 30
Dense	31 to 50
Very dense	Over 50

Standard penetration resistance is the number of blows required to drive a split-barrel sampler with a 2-inch outside diameter 12 inches into the material using a 140-pound hammer falling freely through 30 inches. The sampler is driven through an 18-inch sample interval, and the number of blows is recorded for each 6-inch increment. The density designation of granular soils is obtained by adding the number of blows required to penetrate the last 12 inches of each sample interval. It is important to note that if gravel or rock fragments are broken by the sampler or if rock fragments are lodged in the tip, the resulting blow count will be erroneously high, reflecting a higher density than actually exists. This shall be noted on the log and referenced to the sample number. Granular soils are given the USCS classifications GW, GP, GM, SW, SP, SM, GC, or SC (see Figure 1).

The consistency of cohesive soils is determined by performing field tests and identifying the consistency as shown in Figure 2.

Cohesive soils are given the USCS classifications ML, MH, CL, CH, OL, or OH (see Figure 1).

The consistency of cohesive soils is determined either by blow counts, a pocket penetrometer (values listed in the table as Unconfined Compressive Strength), or by hand by determining the resistance to penetration by the thumb. The pocket penetrometer and thumb determination methods are conducted on a selected sample of the soil, preferably the lowest 0.5 foot of the sample in the split-barrel sampler. The sample shall be broken in half and the thumb or penetrometer pushed into the end of the sample to determine the consistency. Do not determine consistency by attempting to penetrate a rock fragment. If the sample is decomposed rock, it is classified as a soft decomposed rock rather than a hard soil. Consistency shall not be determined solely by blow counts. One of the other methods shall be used in conjunction with it. The designations used to describe the consistency of cohesive soils are shown in Figure 2.



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**FIGURE 2**

**CONSISTENCY FOR COHESIVE SOILS**

Consistency	Standard Penetration Resistance (Blows per Foot)	Unconfined Compressive Strength (Tons/Sq. Foot by pocket penetration)	Field Identification
Very soft	0 to 2	Less than 0.25	Easily penetrated several inches by fist
Soft	2 to 4	0.25 to 0.50	Easily penetrated several inches by thumb
Medium stiff	4 to 8	0.50 to 1.0	Can be penetrated several inches by thumb with moderate effort
Stiff	8 to 15	1.0 to 2.0	Readily indented by thumb but penetrated only with great effort
Very stiff	15 to 30	2.0 to 4.0	Readily indented by thumbnail
Hard	Over 30	More than 4.0	Indented with difficulty by thumbnail



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#### 5.2.4 Weight Percentages

In nature, soils are comprised of particles of varying size and shape, and are combinations of the various grain types. The following terms are useful in the description of soil:

Terms of Identifying Proportion of the Component	Defining Range of Percentages by Weight
Trace	0 - 10 percent
Some	11 - 30 percent
Adjective form of the soil type (e.g., "sandy")	31 - 50 percent

Examples:

- Silty fine sand: 50 to 69 percent fine sand, 31 to 50 percent silt.
- Medium to coarse sand, some silt: 70 to 80 percent medium to coarse sand, 11 to 30 percent silt.
- Fine sandy silt, trace clay: 50 to 68 percent silt, 31 to 49 percent fine sand, 1 to 10 percent clay.
- Clayey silt, some coarse sand: 70 to 89 percent clayey silt, 11 to 30 percent coarse sand.

#### 5.2.5 Moisture

Moisture content is estimated in the field according to four categories: dry, moist, wet, and saturated. In dry soil, there appears to be little or no water. Saturated samples obviously have all the water they can hold. Moist and wet classifications are somewhat subjective and often are determined by the individual's judgment. A suggested parameter for this would be calling a soil wet if rolling it in the hand or on a porous surface liberates water, i.e., dirties or muddies the surface. Whatever method is adopted for describing moisture, it is important that the method used by an individual remains consistent throughout an entire drilling job.

Laboratory tests for water content shall be performed if the natural water content is important.

#### 5.2.6 Stratification

Stratification can only be determined after the sample barrel is opened. The stratification or bedding thickness for soil and rock is depending on grain size and composition. The classification to be used for stratification description is shown in Figure 3.

#### 5.2.7 Texture/Fabric/Bedding

The texture/fabric/bedding of the soil shall be described. Texture is described as the relative angularity of the particles: rounded, subrounded, subangular, and angular. Fabric shall be noted as to whether the particles are flat or bulky and whether there is a particular relation between particles (i.e., all the flat particles are parallel or there is some cementation). The bedding or structure shall also be noted (e.g., stratified, lensed, nonstratified, heterogeneous varved).



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**FIGURE 3**

**BEDDING THICKNESS CLASSIFICATION**

Thickness (metric)	Thickness (Approximate English Equivalent)	Classification
> 1.0 meter	> 3.3'	Massive
30 cm - 1 meter	1.0' - 3.3'	Thick Bedded
10 cm - 30 cm	4" - 1.0'	Medium Bedded
3 cm - 10 cm	1" - 4"	Thin Bedded
1 cm - 3 cm	2/5" - 1"	Very Thin Bedded
3 mm - 1 cm	1/8" - 2/5"	Laminated
1 mm - 3 mm	1/32" - 1/8"	Thinly Laminated
< 1 mm	< 1/32"	Micro Laminated

(Weir, 1973 and Ingram, 1954)



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### 5.2.8 Summary of Soil Classification

In summary, soils shall be classified in a similar manner by each geologist/engineer at a project site. The hierarchy of classification is as follows:

- Density and/or consistency
- Color
- Plasticity (Optional)
- Soil types
- Moisture content
- Stratification
- Texture, fabric, bedding
- Other distinguishing features

### 5.3 Classification of Rocks

Rocks are grouped into three main divisions: sedimentary, igneous and metamorphic. Sedimentary rocks are by far the predominant type exposed at the earth's surface. The following basic names are applied to the types of rocks found in sedimentary sequences:

- Sandstone - Made up predominantly of granular materials ranging between 1/16 to 2 mm in diameter.
- Siltstone - Made up of granular materials less than 1/16 to 1/256 mm in diameter. Fractures irregularly. Medium thick to thick bedded.
- Claystone - Very fine-grained rock made up of clay and silt-size materials. Fractures irregularly. Very smooth to touch. Generally has irregularly spaced pitting on surface of drilled cores.
- Shale - A fissile very fine-grained rock. Fractures along bedding planes.
- Limestone - Rock made up predominantly of calcite ( $\text{CaCO}_3$ ). Effervesces strongly upon the application of dilute hydrochloric acid.
- Coal - Rock consisting mainly of organic remains.
- Others - Numerous other sedimentary rock types are present in lesser amounts in the stratigraphic record. The local abundance of any of these rock types is dependent upon the depositional history of the area. Conglomerate, halite, gypsum, dolomite, anhydrite, lignite, etc. are some of the rock types found in lesser amounts.

In classifying a sedimentary rock the following hierarchy shall be noted:

- Rock type
- Color
- Bedding thickness
- Hardness
- Fracturing
- Weathering
- Other characteristics



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### 5.3.1 Rock Type

As described above, there are numerous types of sedimentary rocks. In most cases, a rock will be a combination of several grain types, therefore, a modifier such as a sandy siltstone, or a silty sandstone can be used. The modifier indicates that a significant portion of the rock type is composed of the modifier. Other modifiers can include carbonaceous, calcareous, siliceous, etc.

Grain size is the basis for the classification of clastic sedimentary rocks. Figure 4 is the Udden-Wentworth classification that will be assigned to sedimentary rocks. The individual boundaries are slightly different than the USCS subdivision for soil classification. For field determination of grain sizes, a scale can be used for the coarse grained rocks. For example, the division between siltstone and claystone may not be measurable in the field. The boundary shall be determined by use of a hand lens. If the grains cannot be seen with the naked eye but are distinguishable with a hand lens, the rock is a siltstone. If the grains are not distinguishable with a hand lens, the rock is a claystone.

### 5.3.2 Color

The color of a rock can be determined in a similar manner as for soil samples. Rock core samples shall be classified while wet, when possible, and air cored samples shall be scraped clean of cuttings prior to color classifications.

Rock color charts shall not be used unless specified by the Project Manager.

### 5.3.3 Bedding Thickness

The bedding thickness designations applied to soil classification (see Figure 3) will also be used for rock classification.

### 5.3.4 Hardness

The hardness of a rock is a function of the compaction, cementation, and mineralogical composition of the rock. A relative scale for sedimentary rock hardness is as follows:

- Soft - Weathered, considerable erosion of core, easily gouged by screwdriver, scratched by fingernail. Soft rock crushes or deforms under pressure of a pressed hammer. This term is always used for the hardness of the saprolite (decomposed rock which occupies the zone between the lowest soil horizon and firm bedrock).
- Medium soft - Slight erosion of core, slightly gouged by screwdriver, or breaks with crumbly edges from single hammer blow.
- Medium hard - No core erosion, easily scratched by screwdriver, or breaks with sharp edges from single hammer blow.
- Hard - Requires several hammer blows to break and has sharp conchoidal breaks. Cannot be scratched with screwdriver.

Note the difference in usage here of the words "scratch" and "gouge." A scratch shall be considered a slight depression in the rock (do not mistake the scraping off of rock flour from drilling with a scratch in the rock itself), while a gouge is much deeper.



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**FIGURE 4**

**GRAIN SIZE CLASSIFICATION FOR ROCKS**

Particle Name	Grain Size Diameter
Cobbles	> 64 mm
Pebbles	4 - 64 mm
Granules	2 - 4 mm
Very Coarse Sand	1 - 2 mm
Coarse Sand	0.5 - 1 mm
Medium Sand	0.25 - 0.5 mm
Fine Sand	0.125 - 0.25 mm
Very Fine Sand	0.0625 - 0.125 mm
Silt	0.0039 - 0.0625 mm

After Wentworth, 1922



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### 5.3.5 Fracturing

The degree of fracturing or brokenness of a rock is described by measuring the fractures or joint spacing. After eliminating drilling breaks, the average spacing is calculated and the fracturing is described by the following terms:

- Very broken (V. BR.) - Less than 2-inch spacing between fractures
- Broken (BR.) - 2-inch to 1-foot spacing between fractures
- Blocky (BL.) - 1- to 3-foot spacing between fractures
- Massive (M.) - 3 to 10-foot spacing between fractures

The structural integrity of the rock can be approximated by calculating the Rock Quality Designation (RQD) of cores recovered. The RQD is determined by adding the total lengths of all pieces exceeding 4 inches and dividing by the total length of the coring run, to obtain a percentage.

Method of Calculating RQD  
(After Deere, 1964)

$$RQD \% = r/l \times 100$$

$r$  = Total length of all pieces of the lithologic unit being measured, which are greater than 4 inches length, and have resulted from natural breaks. Natural breaks include slickensides, joints, compaction slicks, bedding plane partings (not caused by drilling), friable zones, etc.

$l$  = Total length of the coring run.

### 5.3.6 Weathering

The degree of weathering is a significant parameter that is important in determining weathering profiles and is also useful in engineering designs. The following terms can be applied to distinguish the degree of weathering:

- Fresh - Rock shows little or no weathering effect. Fractures or joints have little or no staining and rock has a bright appearance.
- Slight - Rock has some staining which may penetrate several centimeters into the rock. Clay filling of joints may occur. Feldspar grains may show some alteration.
- Moderate - Most of the rock, with exception of quartz grains, is stained. Rock is weakened due to weathering and can be easily broken with hammer.
- Severe - All rock including quartz grains is stained. Some of the rock is weathered to the extent of becoming a soil. Rock is very weak.

### 5.3.7 Other Characteristics

The following items shall be included in the rock description:

- Description of contact between two rock units. These can be sharp or gradational.
- Stratification (parallel, cross stratified).



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- Description of any filled cavities or vugs.
- Cementation (calcareous, siliceous, hematitic).
- Description of any joints or open fractures.
- Observation of the presence of fossils.
- Notation of joints with depth, approximate angle to horizontal, any mineral filling or coating, and degree of weathering.

All information shown on the boring logs shall be neat to the point where it can be reproduced on a copy machine for report presentation. The data shall be kept current to provide control of the drilling program and to indicate various areas requiring special consideration and sampling.

### 5.3.8 Additional Terms Used in the Description of Rock

The following terms are used to further identify rocks:

- Seam - Thin (12 inches or less), probably continuous layer.
- Some - Indicates significant (15 to 40 percent) amounts of the accessory material. For example, rock composed of seams of sandstone (70 percent) and shale (30 percent) would be "sandstone -- some shale seams."
- Few - Indicates insignificant (0 to 15 percent) amounts of the accessory material. For example, rock composed of seam of sandstone (90 percent) and shale (10 percent) would be "sandstone -- few shale seams."
- Interbedded - Used to indicate thin or very thin alternating seams of material occurring in approximately equal amounts. For example, rock composed of thin alternating seams of sandstone (50 percent) and shale (50 percent) would be "interbedded sandstone and shale."
- Interlayered - Used to indicate thick alternating seams of material occurring in approximately equal amounts.

The preceding sections describe the classification of sedimentary rocks. The following are some basic names that are applied to igneous rocks:

- Basalt - A fine-grained extrusive rock composed primarily of calcic plagioclase and pyroxene.
- Rhyolite - A fine-grained volcanic rock containing abundant quartz and orthoclase. The fine-grained equivalent of a granite.
- Granite - A coarse-grained plutonic rock consisting essentially of alkali feldspar and quartz.
- Diorite - A coarse-grained plutonic rock consisting essentially of sodic plagioclase and hornblende.
- Gabbro - A coarse-grained plutonic rock consisting of calcic plagioclase and clinopyroxene. Loosely used for any coarse-grained dark igneous rock.



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The following are some basic names that are applied to metamorphic rocks:

- Slate - A very fine-grained foliated rock possessing a well developed slaty cleavage. Contains predominantly chlorite, mica, quartz, and sericite.
- Phyllite - A fine-grained foliated rock that splits into thin flaky sheets with a silky sheen on cleavage surface.
- Schist - A medium to coarse-grained foliated rock with subparallel arrangement of the micaceous minerals which dominate its composition.
- Gneiss - A coarse-grained foliated rock with bands rich in granular and platy minerals.
- Quartzite - A fine- to coarse-grained nonfoliated rock breaking across grains, consisting essentially of quartz sand with silica cement.

#### 5.4 Abbreviations

Abbreviations may be used in the description of a rock or soil. However, they shall be kept at a minimum. Following are some of the abbreviations that may be used:

C - Coarse	Lt - Light	Yl - Yellow
Med - Medium	BR - Broken	Or - Orange
F - Fine	BL - Blocky	SS - Sandstone
V - Very	M - Massive	Sh - Shale
Sl - Slight	Br - Brown	LS - Limestone
Occ - Occasional	Bl - Black	Fgr - Fine-grained
Tr - Trace		

#### 5.5 Boring Logs and Documentation

This section describes in more detail the procedures to be used in completing boring logs in the field. Information obtained from the preceding sections shall be used to complete the logs. A sample boring log has been provided as Figure 5.

The field geologist/engineer shall use this example as a guide in completing each boring log. Each boring log shall be fully described by the geologist/engineer as the boring is being drilled. Every sheet contains space for 25 feet of log. Information regarding classification details is provided either on the back of the boring log or on a separate sheet, for field use.







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### 5.5.1 Soil Classification

- Identify site name, boring number, job number, etc. Elevations and water level data to be entered when surveyed data is available.
- Enter sample number (from SPT) under appropriate column. Enter depth sample was taken from (1 block = 1 foot). Fractional footages, i.e., change of lithology at 13.7 feet, shall be lined off at the proportional location between the 13- and 14-foot marks. Enter blow counts (Standard Penetration Resistance) diagonally (as shown). Standard penetration resistance is covered in Section 5.2.3.
- Determine sample recovery/sample length as shown. Measure the total length of sample recovered from the split-spoon sampler, including material in the drive shoe. Do not include cuttings or wash material that may be in the upper portion of the sample tube.
- Indicate any change in lithology by drawing a line at the appropriate depth. For example, if clayey silt was encountered from 0 to 5.5 feet and shale from 5.5 to 6.0 feet, a line shall be drawn at this increment. This information is helpful in the construction of cross-sections. As an alternative, symbols may be used to identify each change in lithology.
- The density of granular soils is obtained by adding the number of blows for the last two increments. Refer to Density of Granular Soils Chart on back of log sheet. For consistency of cohesive soils refer also to the back of log sheet - Consistency of Cohesive Soils. Enter this information under the appropriate column. Refer to Section 5.2.3.
- Enter color of the material in the appropriate column.
- Describe material using the USCS. Limit this column for sample description only. The predominate material is described last. If the primary soil is silt but has fines (clay) - use clayey silt. Limit soil descriptors to the following:
  - Trace: 0 - 10 percent
  - Some: 11 - 30 percent
  - And/Or: 31 - 50 percent
- Also indicate under Material Classification if the material is fill or natural soils. Indicate roots, organic material, etc.
- Enter USCS symbol - use chart on back of boring log as a guide. If the soils fall into one of two basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example ML/CL or SM/SP.
- The following information shall be entered under the "Remarks" column and shall include, but is not limited by, the following:
  - Moisture - estimate moisture content using the following terms - dry, moist, wet and saturated. These terms are determined by the individual. Whatever method is used to determine moisture, be consistent throughout the log.



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- Angularity - describe angularity of coarse grained particles using the terms angular, subangular, subrounded, or rounded. Refer to ASTM D 2488 or Earth Manual for criteria for these terms.
- Particle shape - flat, elongated, or flat and elongated.
- Maximum particle size or dimension.
- Water level observations.
- Reaction with HCl - none, weak, or strong.

● Additional comments:

- Indicate presence of mica, caving of hole, when water was encountered, difficulty in drilling, loss or gain of water.
- Indicate odor and Photoionization Detector (PID) or Flame Ionization Detector (FID) reading if applicable.
- Indicate any change in lithology by drawing a line through the lithology change column and indicate the depth. This will help when cross-sections are subsequently constructed.
- At the bottom of the page indicate type of rig, drilling method, hammer size and drop, and any other useful information (i.e., borehole size, casing set, changes in drilling method).
- Vertical lines shall be drawn (as shown in Figure 5) in columns 6 to 8 from the bottom of each sample to the top of the next sample to indicate consistency of material from sample to sample, if the material is consistent. Horizontal lines shall be drawn if there is a change in lithology, then vertical lines drawn to that point.
- Indicate screened interval of well, as needed, in the lithology column. Show top and bottom of screen. Other details of well construction are provided on the well construction forms.

### 5.5.2 Rock Classification

- Indicate depth at which coring began by drawing a line at the appropriate depth. Indicate core run depths by drawing coring run lines (as shown) under the first and fourth columns on the log sheet. Indicate RQD, core run number, RQD percent, and core recovery under the appropriate columns.
- Indicate lithology change by drawing a line at the appropriate depth as explained in Section 5.5.1.
- Rock hardness is entered under designated column using terms as described on the back of the log or as explained earlier in this section.



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- Enter color as determined while the core sample is wet; if the sample is cored by air, the core shall be scraped clean prior to describing color.
- Enter rock type based on sedimentary, igneous or metamorphic. For sedimentary rocks use terms as described in Section 5.3. Again, be consistent in classification. Use modifiers and additional terms as needed. For igneous and metamorphic rock types use terms as described in Sections 5.3.8.
- Enter brokenness of rock or degree of fracturing under the appropriate column using symbols VBR, BR, BL, or M as explained in Section 5.3.5 and as noted on the back of the Boring Log.
- The following information shall be entered under the remarks column. Items shall include but are not limited to the following:
  - Indicate depths of joints, fractures and breaks and also approximate to horizontal angle (such as high, low), i.e., 70° angle from horizontal, high angle.
  - Indicate calcareous zones, description of any cavities or vugs.
  - Indicate any loss or gain of drill water.
  - Indicate drop of drill tools or change in color of drill water.
- Remarks at the bottom of Boring Log shall include:
  - Type and size of core obtained.
  - Depth casing was set.
  - Type of rig used.
- As a final check the boring log shall include the following:
  - Vertical lines shall be drawn as explained for soil classification to indicate consistency of bedrock material.
  - If applicable, indicate screened interval in the lithology column. Show top and bottom of screen. Other details of well construction are provided on the well construction forms.

### 5.5.3 Classification of Soil and Rock from Drill Cuttings

The previous sections describe procedures for classifying soil and rock samples when cores are obtained. However, some drilling methods (air/mud rotary) may require classification and borehole logging based on identifying drill cuttings removed from the borehole. Such cuttings provide only general information on subsurface lithology. Some procedures that shall be followed when logging cuttings are:

- Obtain cutting samples at approximately 5-foot intervals, sieve the cuttings (if mud rotary drilling) to obtain a cleaner sample, place the sample into a small sample bottle or "zip lock"



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bag for future reference, and label the jar or bag (i.e. hole number, depth, date, etc.). Cuttings shall be closely examined to determine general lithology.

- Note any change in color of drilling fluid or cuttings, to estimate changes in lithology.
- Note drop or chattering of drilling tools or a change in the rate of drilling, to determine fracture locations or lithologic changes.
- Observe loss or gain of drilling fluids or air (if air rotary methods are used), to identify potential fracture zones.
- Record this and any other useful information onto the boring log as provided in Figure 1.

This logging provides a general description of subsurface lithology and adequate information can be obtained through careful observation of the drilling process. It is recommended that split-barrel and rock core sampling methods be used at selected boring locations during the field investigation to provide detailed information to supplement the less detailed data generated through borings drilled using air/mud rotary methods.

## 5.6 Review

Upon completion of the borings logs, copies shall be made and reviewed. Items to be reviewed include:

- Checking for consistency of all logs.
- Checking for conformance to the guideline.
- Checking to see that all information is entered in their respective columns and spaces.

## 6.0 REFERENCES

Unified Soil Classification System (USCS).

ASTM D2488, 1985.

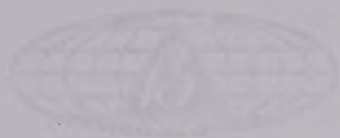
Earth Manual, U.S. Department of the Interior, 1974.

## 7.0 RECORDS

Originals of the boring logs shall be retained in the project files.







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## 1.0 PURPOSE

This procedure provides general guidance and information pertaining to proper monitoring well design, installation, and development.

## 2.0 SCOPE

This procedure is applicable to the construction of permanent monitoring wells. The methods described herein may be modified by project-specific requirements for monitoring well construction. In addition, many regulatory agencies have specific regulations pertaining to monitoring well construction and permitting. These requirements must be determined during the project planning phases of the investigation, and any required permits must be obtained before field work begins. Innovative monitoring well installation techniques, which typically are not used, will be discussed only generally in this procedure.

## 3.0 GLOSSARY

Monitoring Well - A well which is properly screened (if screening is necessary, e.g., open borehole), cased, and sealed which is capable of providing a groundwater level and groundwater sample representative of the zone being monitored.

Piezometer - A pipe or tube inserted into the water bearing zone, typically open to water flow at the bottom and to the atmosphere at the top, and used to measure water level elevations. Piezometers may range in size from 1/2-inch-diameter plastic tubes to well points or monitoring wells.

Potentiometric Surface - The surface representative of the level to which water will rise in a well cased to the screened aquifer.

Well Point (Drive Point) - A screened or perforated tube (Typically 1-1/4 or 2 inches in diameter) with a solid, conical, hardened point at one end, which is attached to a riser pipe and driven into the ground with a sledge hammer, drop weight, or mechanical vibrator. Well points may be used for groundwater injection and recovery, as piezometers (i.e., to measure water levels) or to provide groundwater samples for water quality data.

## 4.0 RESPONSIBILITIES

Driller - The driller provides adequate and operable equipment, sufficient quantities of materials, and an experienced and efficient labor force capable of performing all phases of proper monitoring well installation and construction. The driller may also be responsible for obtaining, in advance, any required permits for monitoring well installation and construction.

Rig Geologist - The rig geologist supervises and documents well installation and construction performed by the driller, and insures that well construction is adequate to provide representative groundwater data from the monitored interval. Geotechnical engineers, field technicians, or other suitable trained personnel may also serve in this capacity.



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## 5.0 PROCEDURES

### 5.1 Equipment/Items Needed

Below is a list of items that may be needed when installing a monitoring well:

- Health and safety equipment as required by the Site Safety Officer.
- Well drilling and installation equipment with associated materials (typically supplied by the driller).
- Hydrogeologic equipment (weighted engineer's tape, water level indicator, retractable engineers rule, electronic calculator, clipboard, mirror and flashlight - for observing downhole activities, paint and ink marker for marking monitoring wells, sample jars, well installation forms, and a field notebook).
- Drive point installations tools (sledge hammer, drop hammer, or mechanical vibrator; tripod, pipe wrenches, drive points, riser pipe, and end caps).

### 5.2 Well Design

The objectives for each monitoring well and its intended use must be clearly defined before the monitoring system is designed. Within the monitoring system, different monitoring wells may serve different purposes and, therefore, require different types of construction. During all phases of the well design, attention must be given to clearly documenting the basis for design decisions, the details of well construction, and the materials to be used. The objectives for installing the monitoring wells may include:

- Determining groundwater flow directions and velocities.
- Sampling or monitoring for trace contaminants.
- Determining aquifer characteristics (e.g., hydraulic conductivity).

Siting of monitoring wells shall be performed after a preliminary estimation of the groundwater flow direction. In most cases, groundwater flow and potential well locations can be determined through the review of geologic data and the site terrain. In addition, data from production wells or other monitoring wells in the area may be used to determine the groundwater flow direction. If these methods cannot be used, piezometers, which are relatively inexpensive to install, may have to be installed in a preliminary investigative phase to determine groundwater flow direction.

#### 5.2.1 Well Depth, Diameter, and Monitored Interval

The well depth, diameter, and monitored interval must be tailored to the specific monitoring needs of each investigation. Specification of these items generally depends on the purpose of the monitoring system and the characteristics of the hydrogeologic system being monitored. Wells of different depth, diameter, and monitored interval can be employed in the same groundwater monitoring system. For instance, varying the monitored interval in several wells, at the same location (cluster wells) can help to determine the vertical gradient and the levels at which contaminants are present. Conversely, a fully penetrating well is usually not used to quantify or vertically locate a contaminant plume, since groundwater samples collected in wells that are screened over the full thickness of the water-bearing zone will be representative of average conditions across the entire monitored interval. However, fully penetrating wells can be used to establish the existence of contamination in the water-bearing zone. The



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well diameter desired depends upon the hydraulic characteristics of the water-bearing zone, sampling requirements, drilling method and cost.

The decision concerning the monitored interval and well depth is based on the following (and possibly other) information:

- The vertical location of the contaminant source in relation to the water-bearing zone.
- The depth, thickness and uniformity of the water-bearing zone.
- The anticipated depth, thickness, and characteristics (e.g., density relative to water) of the contaminant plume.
- Fluctuation in groundwater levels (due to pumping, tidal influences, or natural recharge/discharge events).
- The presence and location of contaminants encountered during drilling.
- Whether the purpose of the installation is for determining existence or non-existence of contamination or if a particular stratigraphic zone is being investigated.
- The analysis of borehole geophysical logs.

In most situations where groundwater flow lines are horizontal, depending on the purpose of the well and the site conditions, monitored intervals are 20 feet or less. Shorter screen lengths (1 to 2 feet) are usually required where flow lines are not horizontal, (i.e., if the wells are to be used for accurate measurement of the potentiometric head at a specific point).

Many factors influence the diameter of a monitoring well. The diameter of the monitoring well depends on the application. In determining well diameter, the following needs must be considered:

- Adequate water volume for sampling.
- Drilling methodology.
- Type of sampling device to be used.
- Costs.

Standard monitoring well diameters are 2, 4, 6, or 8 inches. However, drive points are typically 1-1/4 or 2 inches in diameter. For monitoring programs which require screened monitoring wells, either a 2-inch or 4-inch-diameter well is preferred. Typically, well diameters greater than 4 inches are used in monitoring programs in which open-hole monitoring wells are required. In the smaller diameter wells, the volume of stagnant water in the well is minimized, and well construction costs are reduced, however, the type of sampling devices that can be used are limited. In specifying well diameter, sampling requirements must be considered (up to a total of 4 gallons of water may be required for a single sample to account for full organic and inorganic analyses, and split samples). The volume of water in the monitoring well available for sampling is dependent on the well diameter as follows:



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Casing Inside Diameter (Inch)	Standing Water Depth to Obtain 1 Gallon Water (Feet)	Total Depth of Standing Water for 4 Gallons (Feet)
2	6.13	25
4	1.53	6
6	0.68	3

However, if a specific well recharges quickly after purging, then well diameter may not be an important factor regarding sample volume requirements.

Pumping tests for determining aquifer characteristics may require larger diameter wells; however, in small-diameter wells in-situ permeability tests can be performed during drilling or after well installation is completed.

#### 5.2.2 Riser Pipe and Screen Materials

Well materials are specified by diameter, type of material, and thickness of pipe. Well screens require an additional specification of slot size. Thickness of pipe is referred to as "schedule" for polyvinyl chloride (PVC) casing and is usually Schedule 40 (thinner wall) or 80 (thicker wall). Steel pipe thickness is often referred to as "Strength" and Standard Strength is usually adequate for monitoring well purposes. With larger diameter pipe, the wall thickness must be greater to maintain adequate strength. The required thickness is also dependent on the method of installation; risers for drive points require greater strength than wells installed inside drilled borings.

The selection of well screen and riser materials depends on the method of drilling, the type of subsurface materials the well penetrates, the type of contamination expected, and natural water quality and depth. Cost and the level of accuracy required are also important. The materials generally available are Teflon, stainless steel, PVC galvanized steel, and carbon steel. Each has advantages and limitations (see Attachment A of this guideline for an extensive presentation on this topic). The two most commonly used materials are PVC and stainless steel for wells in which screens are installed. Properties of these two materials are compared in Attachment B. Stainless steel is preferred where trace metals or organic sampling is required; however, costs are high. Teflon materials are extremely expensive, but are relatively inert and provide the least opportunity for water contamination due to well materials. PVC has many advantages, including low cost, excellent availability, light weight, and ease of manipulation; however, there are also some questions about organic chemical sorption and leaching that are currently being researched (see Barcelona et al., 1983). Concern about the use of PVC can be minimized if PVC wells are used strictly for geohydrologic measurements and not for chemical sampling. The crushing strength of PVC may limit the depth of installation, but Schedule 80 materials normally used for wells greater than 50 feet deep may overcome some of the problems associated with depth. However, the smaller inside diameter of Schedule 80 pipe may be an important factor when considering the size of bailers or pumps required for sampling or testing. Due to this problem, the minimum well pipe size recommended for Schedule 80 wells is 4-inch I.D.

Screens and risers may have to be decontaminated before use because oil-based preservatives and oil used during thread cutting and screen manufacturing may contaminate samples. Metal pipe, may corrode and release metal ions or chemically react with organic constituents, but this is considered by some to be less of a problem than the problem associated with PVC material. Galvanized steel is not



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recommended where samples may be collected for metal analyses, as zinc and cadmium levels in groundwater samples may become elevated from leaching of the zinc coating.

Threaded, flush-joint casing is most often preferred for monitoring well applications. PVC, Teflon, and steel can all be obtained with threaded joints at slightly more costs. Welded-joint steel casing is also acceptable. Glued PVC may release organic contaminants into the well, and therefore, should not be used if the well is to be sampled for organic constituents.

When the water-bearing zone is in consolidated bedrock, such as limestone or fractured granite, a well screen is often not necessary (the well is simply an open hole in bedrock). Unconsolidated materials, such as sands, clay, and silts require a screen. A screen slot size of 0.010 or 0.020 inch is generally used when a screen is necessary and the screened interval is artificially packed with a fine sand. The slot size controls the quantity of water entering the well and prevents entry of natural materials or sand pack. The screen shall pass no more than 10 percent of the pack material, or in-situ aquifer material. The rig geologist shall specify the combination of screen slot size and sand pack which will be compatible with the water-bearing zone, to maximize groundwater inflow and minimize head losses and movement of fines into the wells. For example, as a standard procedure, a Morie No. 1 or No. 10 to No. 20 U.S. Standard Sieve size filter pack is typically appropriate for a 0.020-inch slot screen; however, a No. 20 to No. 40 U.S. Standard Sieve size filter pack is typically appropriate for a 0.010-inch slot screen.

### 5.2.3 Annular Materials

Materials placed in the annular space between the borehole and riser pipe and screen include a sand pack when necessary, a bentonite seal, and cement-bentonite grout. The sand pack is usually a fine-to medium-grained poorly graded, silica sand and should relate to the grain size of the aquifer sediments. The quantity of sand placed in the annular space is dependent upon the length of the screened interval, but should always extend at least 1 foot above the top of the screen. At least 1 to 3 feet of bentonite pellets or equivalent shall be placed above the sand pack. Cement-bentonite grout (or equivalent) is then placed to extent from the top of the bentonite pellets to the ground surface.

On occasion, and with the concurrence of the involved regulatory agencies, monitoring wells may be packed naturally (i.e., no artificial sand pack installed), and the natural formation material is allowed to collapse around the well screen after the well is installed. This method has been used where the formation material itself is a relatively uniform grain size, or when artificial sand packing is not possible due to borehole collapse.

Bentonite expands by absorbing water and provides a seal between the screened interval and the overlying portion of the annular space and formation. Cement-bentonite grout is placed on top of the bentonite pellets extending to the surface. The grout effectively seals the well and eliminates the possibility for surface infiltration reaching the screened interval. Grouting also replaces material removed during drilling and prevents hole collapse and subsidence around the well. A tremie pipe should be used to introduce grout from the bottom of the hole upward, to prevent bridging, and to provide a better seal. However, in shallow boreholes that don't collapse, it may be more practical to pour the grout from the surface without a tremie pipe.

Grout is a general term which has several different connotations. For all practical purposes within the monitoring well installation industry, grout refers to the solidified material which is installed and occupies the annular space above the bentonite pellet seal. Grout, most of the time, is made up of two assemblages of material, (e.g., cement-bentonite). A cement-bentonite grout normally is a mixture of cement, bentonite, and water at a ratio of one 90-pound bag of Portland Type I cement, plus



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3 to 5 pounds of granular or flake-type bentonite, and 6 gallons of water. A neat cement consists of one ninety-pound bag of Portland Type I cement and 6 gallons of water.

In certain cases, the borehole may be drilled to a depth greater than the anticipated well installation depth. For these cases, the well shall be backfilled to the desired depth with bentonite pellets or equivalent. A short (1- to 2-foot) section of capped riser pipe sump is sometimes installed immediately below the screen, as a silt reservoir, when significant post-development silting is anticipated. This will ensure that the entire screen surface remains unobstructed.

#### **5.2.4 Protective Casing**

When the well is completed and grouted to the surface, a protective steel casing is often placed over the top of the well. This casing generally has a hinged cap and can be locked to prevent vandalism. A vent hole shall be provided in the cap to allow venting of gases and maintain atmospheric pressure as water levels rise or fall in the well. The protective casing has a larger diameter than the well and is set into the wet cement grout over the well upon completion. In addition, one hole is drilled just above the cement collar through the protective casing which acts as a weep hole for the flow of water which may enter the annulus during well development, purging, or sampling.

A protective casing which is level with the ground surface is used in roadway or parking lot applications where the top of a monitoring well must be below the pavement. The top of the riser pipe is placed 4 to 5 inches below the pavement, and a locking protective casing is cemented in place to 3 inches below the pavement. A large diameter protective sleeve is set into the wet cement around the well with the top set level with the pavement. A manhole-type lid placed over the protective sleeve. The cement should be slightly mounded to direct pooled water away from the well head.

### **5.3 Monitoring Well Installation**

Pertinent data regarding monitoring well installation shall be recorded on log sheets as depicted and discussed in SOP SA-6.3. Attachments to this referenced SOP illustrate terms and physical construction of various types of monitoring wells.

#### **5.3.1 Monitoring Wells in Unconsolidated Sediments**

After the borehole is drilled to the desired depth, well installation can begin. The procedure for well installation will partially be dictated by the stability of the formation in which the well is being placed. If the borehole collapses immediately after the drilling tools are withdrawn, then a temporary casing must be installed and well installation will proceed through the center of the temporary casing, and continue as the temporary casing is withdrawn from the borehole. In the case of hollow-stem auger drilling, the augers will act to stabilize the borehole during well installation.

Before the screen and riser pipe are lowered into the borehole, all pipe and screen sections should be measured with an engineer's rule to ensure proper placement. When measuring sections, the threads on one end of the pipe or screen must be excluded while measuring, since the pipe and screen sections are screwed flush together.

After the screen and riser pipe are lowered through the temporary casing, the sand pack can be installed. A weighted tape measure must be used during the installation procedure to carefully monitor installation progress. The sand is poured into the annulus between the riser pipe and temporary casing, as the casing is withdrawn. Sand should always be kept within the temporary casing during withdrawal in order to ensure an adequate sand pack. However, if too much sand is within the temporary casing (greater



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than 1 foot above the bottom of the casing) bridging between the temporary casing and riser pipe may occur.

After the sand pack is installed to the desired depth (at least 1 foot above the top of the screen), then the bentonite pellet seal (or equivalent), can be installed in the same manner as the sand pack. At least 1 to 3 feet of bentonite pellets should be installed above the sand pack.

The cement-bentonite grout is then mixed and either poured or tremied into the annulus as the temporary casing or augers are withdrawn. Finally, the protective casing can be installed as detailed in Section 5.2.4.

In stable formations where borehole collapse does not occur, the well can be installed as discussed above, and the use of a temporary casing is not needed. However, centralizers may have to be installed, one above and one below the screen, to assure enough annular space for sand pack placement.

### 5.3.2 Confining Layer Monitoring Wells

When drilling and installing a well in a confined aquifer, proper well installation techniques must be applied to avoid cross contamination between the unconfined and confined aquifer. Under most conditions, this can be accomplished by installing double-cased wells. This is accomplished by drilling a large-diameter boring through the upper aquifer, 1 to 3 feet into the underlying confining layer, and setting and pressure grouting or tremie grouting the outer casing into the confining layer. The grout material must fill the space between the native material and the outer casing. A smaller diameter boring is then continued through the confining layer for installation of the monitoring well as detailed for overburden monitoring wells (with the exception of not using a temporary casing during installation). Sufficient time (determined by the rig geologist), must be allowed for setting of the grout prior to drilling through the confined layer.

### 5.3.3 Bedrock Monitoring Wells

When installing bedrock monitoring wells, a large diameter boring is drilled through the overburden and approximately 5 feet into the bedrock. A casing (typically steel) is installed and either pressure grouted or tremie grouted in place. After the grout has cured, a smaller diameter boring is continued through the bedrock to the desired depth. If the boring does not collapse, the well can be left open, and a screen is not necessary. If the boring collapses, then a screen is required and can be installed as detailed for overburden monitoring wells. However, if a screen is to be used, then the casing which is installed through the overburden and into the bedrock does not require grouting and can be installed temporary until final well installation is completed.

### 5.3.4 Drive Points

Drive points can be installed with either a sledge hammer, drop hammer, or a mechanical vibrator. The screen is threaded and tightened onto the riser pipe with pipe wrenches. The drive point is simply pounded into the subsurface to the desired depth. If a heavy drop hammer is used, then a tripod and pulley setup is required to lift the hammer. Drive points typically cannot be driven to depths exceeding 10 feet.

### 5.3.5 Innovative Monitoring Well Installation Techniques

Certain innovative sampling devices have proven advantageous. These devices are essentially screened samplers installed in a borehole with only one or two small-diameter tubes extending to the surface.



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Manufacturers of these types of samplers claim that four samplers can be installed in a 3-inch-diameter borehole. This reduces drilling costs, decreases the volume of stagnant water, and provides a sampling system that minimizes cross-contamination from sampling equipment. These samplers also perform well when the water table is within 25 feet of the surface (the typical range of suction pumps). Two manufacturers of these samplers are Timco Manufacturing Company, Inc., of Prairie du Sac, Wisconsin, and BARCAD Systems, Inc., of Concord, Massachusetts. Each manufacturer offers various construction materials.

Two additional types of multilevel sampling systems have been developed. Both employ individual screened openings through a small-diameter casing. One of these systems (marketed by Westbay Instruments Ltd. of Vancouver, British Columbia, Canada) uses a screened port and a sampling probe to obtain samples and head measurements or perform permeability tests. This system allows sampling ports at intervals as close as 5 feet, if desired, in boreholes from 3 to 4.8 inches in diameter.

The second system, developed at the University of Waterloo at Waterloo, Ontario, Canada, requires field assembly of the individual sampling ports and tubes that actuate a simple piston pump and force the samples to the surface. Where the depth to ground water is less than 25 feet, the piston pumps are not required. The assembly is made of easily obtained materials; however, the cost of labor to assemble these monitoring systems may not be cost-effective.

#### **5.4 Well Development Methods**

The purpose of well development is to stabilize and increase the permeability of the gravel pack around the well screen, and to restore the permeability of the formation which may have been reduced by drilling operations. Wells are typically developed until all fine material and drilling water is removed from the well. Sequential measurements of pH, conductivity and temperature taken during development may yield information (stabilized values) that sufficient development is reached. The selection of the well development method shall be made by the rig geologist and is based on the drilling methods, well construction and installation details, and the characteristics of the formation that the well is screened in. The primary methods of well development are summarized below. A more detailed discussion may be found in Driscoll (1986).

##### **5.4.1 Overpumping and Backwashing**

Wells may be developed by alternatively drawing the water level down at a high rate (by pumping or bailing) and then reversing the flow direction (backwashing) so that water is passing from the well into the formation. This back and forth movement of water through the well screen and gravel pack serves to remove fines from the formation immediately adjacent to the well, while preventing bridging (wedging) of sand grains. Backwashing can be accomplished by several methods, including pouring water into the well and then bailing, starting and stopping a pump intermittently to change water levels, or forcing water into the well under pressure through a water-tight fitting ("rawhiding"). Care should be taken when backwashing not to apply too much pressure, which could damage or destroy the well screen.

##### **5.4.2 Surging with a Surge Plunger**

A surge plunger (also called a surge block) is approximately the same diameter as the well casing and is used to agitate the water, causing it to move in and out of the screens. This movement of water pulls fine materials into the well, where they may be removed by any of several methods, and prevents bridging of sand particles in the gravel pack. There are two basic types of surge plungers; solid and valved surge plungers. In formations with low yields, a valved surge plunger may be preferred, as solid



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plungers tend to force water out of the well at a greater rate than it will flow back in. Valved plungers are designed to produce a greater inflow than outflow of water during surging.

**5.4.3 Compressed Air**

Compressed air can be used to develop a well by either of two methods: backwashing or surging. Backwashing is done by forcing water out through the screens, using increasing air pressure inside a sealed well, then releasing the pressurized air to allow the water to flow back into the well. Care should be taken when using this method so that the water level does not drop below the top of the screen, thus reducing well yield. Surging, or the "open well" method, consists of alternately releasing large volumes of air suddenly into an open well below the water level to produce a strong surge by virtue of the resistance of water head, friction, and inertia. Pumping of the well is subsequently done using the air lift method.

**5.4.4 High Velocity Jetting**

In the high velocity jetting method, water is forced at high velocities from a plunger-type device and through the well screen to loosen fine particles from the sand pack and surrounding formation. The jetting tool is slowly rotated and raised and lowered along the length of the well screen to develop the entire screened area. Jetting using a hose lowered into the well may also be effective. The fines washed into the screen during this process can then be bailed or pumped from the well.

**6.0 REFERENCES**

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Barcelona, M. J., P. P. Gibb and R. A. Miller, 1983. A Guide to the selection of Materials for Monitoring Well Construction and Groundwater Sampling. ISWS Contract Report 327, Illinois State Water Survey, Champaign, Illinois.

U.S. EPA, 1980. Procedures Manual for Groundwater Monitoring of Solid Waste Disposal Facilities. Publication SW-611, Office of Solid Waste, U.S. EPA, Washington, D.C.

Driscoll, Fletcher G., 1986. Groundwater and Wells. Johnson Division, St. Paul, Minnesota, 1989.

**7.0 RECORDS**

A critical part of monitoring well installation is recording of significant details and events in the site logbook or field notebook. The geologist must record the exact depths of significant hydrogeological features screen placement, gravel pack placement, and bentonite placement.

A Monitoring Well Sheet (see Attachments to SOP SA-6.3) shall be completed thus ensuring the uniform recording of data for each installation and rapid identification of missing information. Well depth, length, materials of construction, length and openings of screen, length and type of riser, and depth and type of all backfill materials shall be recorded. Additional information shall include location, installation date, problems encountered, water levels before and after well installation, cross-reference to the geologic boring log, and methods used during the installation and development process. Documentation is very important to prevent problems involving questionable sample validity. Somewhat different information



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will need to be recorded depending on whether the well is completed in overburden, in a confined layer, in bedrock with a cased well, or as an open hole in bedrock.

The quantities of sand, bentonite, and grout placed in the well are also important. The geologist shall calculate the annular space volume and have a general idea of the quantity of material needed to fill the annular space. Volumes of backfill significantly higher than the calculated volume may indicate a problem such as a large cavity, while a smaller backfill volume may indicate a cave-in. Any problems with rig operation or down-time shall be recorded and may affect the driller's final fee.

Material	Type of Comp. Material					
	PVC Flexible	PE Comp	PE Unsat	PFA	Viton*	Silicone Neoprene
Hydrochloric Acid	97	97	100	97	95	87
Fluoric Acid	90	94	96	78	78	75
Hydrofluoric Acid	100	100	100	85	100	75
Acetic Acid	65	71	60	49	78	46
Phosphoric Acid	98	90	84	86	78	75

\*Viton is a registered trademark of DuPont.

1. Teflon  
2. Polypropylene (PP)  
3. PVC Flexible/PE Unsat  
4. Viton

Testimony of DuPont

Source: Testimony of Dr. [Name]



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### ATTACHMENT A

#### RELATIVE COMPATIBILITY OF RIGID WELL CASING MATERIAL (PERCENT)

Potentially-Deteriorating Substance	Type of Casing Material						
	PVC 1	Galvanized Steel	Carbon Steel	Lo-carbon Steel	Stainless Steel 304	Stainless Steel 316	Teflon*
Buffered Weak Acid	100	56	51	59	97	100	100
Weak Acid	98	59	43	47	96	100	100
Mineral Acid/ High Solids Content	100	48	57	60	80	82	100
Aqueous/Organic Mixtures	64	69	73	73	98	100	100
Percent Overall Rating	91	58	56	59	93	96	100

#### Preliminary Ranking of Rigid Materials:

- |    |                     |   |                  |
|----|---------------------|---|------------------|
| 1  | Teflon <sup>®</sup> | 5 | Lo-Carbon Steel  |
| 2  | Stainless Steel 316 | 6 | Galvanized Steel |
| 3. | Stainless Steel 304 | 7 | Carbon Steel     |
| 4  | PVC 1               |   |                  |

\* Trademark of DuPont

#### RELATIVE COMPATIBILITY OF SEMI-RIGID OR ELASTOMERIC MATERIALS (PERCENT)

Potentially- Deteriorating Substance	Type of Casing Material								
	PVC Flexible	PP	PE Conv.	PE Linear	PMM	Viton <sup>®</sup> *	Silicone	Neoprene	Teflon <sup>®</sup> *
Buffered Weak Acid	97	97	100	97	90	92	87	85	100
Weak Acid	92	90	94	96	78	78	75	75	100
Mineral Acid/ High Solids Content	100	100	100	100	95	100	78	82	100
Aqueous/Organic Mixtures	62	71	40	60	49	78	49	44	100
Percent Overall Rating	88	90	84	88	78	87	72	72	100

#### Preliminary Ranking of Semi-Rigid or Elastomeric Materials:

- |    |                        |   |                        |
|----|------------------------|---|------------------------|
| 1  | Teflon <sup>®</sup>    | 5 | PE Conventional        |
| 2  | Polypropylene (PP)     | 6 | Plexiglas/Lucite (PMM) |
| 3. | PVC Flexible/PE Linear | 7 | Silicone/Neoprene      |
| 4  | Viton <sup>®</sup>     |   |                        |

\* Trademark of DuPont

Source: Barcelona et al., 1983



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## ATTACHMENT B

### COMPARISON OF STAINLESS STEEL AND PVC FOR MONITORING WELL CONSTRUCTION

Characteristic	Stainless Steel	PVC
Strength	Use in deep wells to prevent compression and closing of screen/riser.	Use when shear and compressive strength are not critical.
Weight	Relatively heavier.	Light-weight; floats in water.
Cost	Relatively expensive.	Relatively inexpensive.
Corrosivity	Deteriorates more rapidly in corrosive water.	Non-corrosive -- may deteriorate in presence of ketones, aromatics, alkyl sulfides, or some chlorinated hydrocarbons.
Ease of Use	Difficult to adjust size or length in the field.	Easy to handle and work with in the field.
Preparation for Use	Should be steam cleaned organics will be subsequently sampled.	Never use glue fittings -- pipes should be threaded or pressure fitted. Should be steam cleaned when used for monitoring wells.
Interaction with Contaminants*	May sorb organic or inorganic substances when oxidized.	May sorb or release organic substances.

\* See also Attachment A.














BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

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Applicability B&R Environmental, NE	
Prepared Earth Sciences Department	
Approved D. Senovich 	

Subject

GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER  
QUALITY TESTING

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## 1.0 PURPOSE

The purpose of this procedure is to provide general reference information regarding the sampling of groundwater wells.

## 2.0 SCOPE

This procedure provides information on proper sampling equipment, onsite water quality testing, and techniques for groundwater sampling. Review of the information contained herein will facilitate planning of the field sampling effort by describing standard sampling techniques. The techniques described shall be followed whenever applicable, noting that site-specific conditions or project-specific plans may require modifications to methodology.

## 3.0 GLOSSARY

Conductance - The conductance of a conductor 1 centimeter long and 1 square centimeter in cross-sectional area. For groundwater measurements, a volume of water contained in a 1 cm x 1 cm sample container (the water acts as the conductor). Conductivity and specific conductance are used synonymously.

Electrolytic Cell - An electrochemical cell in which electrical energy is supplied from an external source. This cell functions in much the same way as a galvanic cell, only the current flows in the opposite direction due to the external source of applied voltage. Electrolytic cells are used in dissolved oxygen measurement.

Galvanic Cell - A electrochemical cell in which chemical energy is spontaneously converted to electrical energy. The electrical energy produced is supplied to an external circuit. Galvanic cells are used in dissolved oxygen measurement.

Ohm - Standard unit of electrical resistance (R). Used in specific conductance measurement. A siemen (or umho) is the standard unit of electrical conductance, the inverse of the ohm.

Oxidation-Reduction Potential (ORP) - A measure of the activity ratio of oxidizing and reducing species as determined by the electromotive force developed by a noble metal electrode, immersed in water, as referenced against a standard hydrogen electrode.

pH - The negative logarithm (base 10) of the hydrogen ion activity. The hydrogen ion activity is related to the hydrogen ion concentration, and, in a relatively weak solution, the two are nearly equal. Thus, for all practical purposes, pH is a measure of the hydrogen ion concentration.

pH Paper - Indicator paper that turns different colors depending on the pH of the solution to which it is exposed. Comparison with color standards supplied by the manufacturer will then give an indication of the solution's pH.

Resistance - A measure of the solution's ability to oppose the passage of electrical current. For metals and solutions, resistance is defined by Ohm's Law,  $E = IR$ , where E is the potential difference, I is the current, and R is the resistance. Used in measurement of specific conductance.



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#### 4.0 RESPONSIBILITIES

Project Hydrogeologist - Responsible for selecting and detailing the specific groundwater sampling techniques, onsite water quality testing (type, frequency, and location), and equipment to be used, and providing detailed input in this regard to the project plan documents. The project hydrogeologist is also responsible for properly briefing and overseeing the performance of the site sampling personnel.

Project Geologist - is primarily responsible for the proper acquisition of the groundwater samples. He/she is also responsible for the actual analyses of onsite water quality samples, as well as instrument calibration, care, and maintenance. When appropriate, such responsibilities may be performed by other qualified personnel (e.g., field technicians).

#### 5.0 PROCEDURES

##### 5.1 General

To be useful and accurate, a groundwater sample must be representative of the particular zone of the water being sampled. The physical, chemical, and bacteriological integrity of the sample must be maintained from the time of sampling to the time of analysis in order to keep any changes in water quality parameters to a minimum.

Methods for withdrawing samples from completed wells include the use of pumps, compressed air, bailers, and various types of samplers. The primary considerations in obtaining a representative sample of the groundwater are to avoid collection of stagnant (standing) water in the well and to avoid physical or chemical alteration of the water due to sampling techniques. In a non-pumping well, there will be little or no vertical mixing of water in the well pipe or casing, and stratification will occur. The well water in the screened section will mix with the groundwater due to normal flow patterns, but the well water above the screened section will remain isolated and become stagnant. To safeguard against collecting non-representative stagnant water in a sample, the following approach shall be followed prior to sample acquisition:

1. All monitoring wells shall be purged prior to obtaining a sample. Evacuation of three to five volumes is recommended prior to sampling. In a high-yielding groundwater formation and where there is no stagnant water in the well above the screened section, extensive evacuation prior to sample withdrawal is not as critical.
2. For wells that can be purged dry, the well shall be evacuated and allowed to recover prior to sample acquisition. If the recovery rate is fairly rapid, evacuation of more than one volume of water is required.
3. For high-yielding monitoring wells which cannot be evacuated to dryness, there is no absolute safeguard against contaminating the sample with stagnant water. One of the following techniques shall be used to minimize this possibility:
  - A submersible pump or the intake line of a surface pump or bailer shall be placed just below the water surface when removing the stagnant water and lowered as the water level drops. Three to five volumes of water shall be removed to provide reasonable assurance that all stagnant water has been evacuated. Once this is accomplished, a bailer or other approved device may be used to collect the sample for analysis.



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- The intake line of the sampling pump (or the submersible pump itself) shall be placed near the bottom of the screened section, and approximately one casing volume of water shall be pumped from the well at a low purge rate, equal to the well's recovery rate (low flow sampling).

Stratification of contaminants may exist in the aquifer. Concentration gradients as a result of mixing and dispersion processes, layers of variable permeability, and the presence of separate-phase product (i.e., floating hydrocarbons) may cause stratification. Excessive pumping or improper sampling methods can dilute or increase the contaminant concentrations in the recovered sample compared to what is representative of the integrated water column as it naturally occurs at that point, thus the result is the collection of a non-representative sample.

## 5.2 Sampling, Monitoring, and Evacuation Equipment

Sample containers shall conform with the guidelines expressed in SOP SA-6.1.

The following equipment shall be on hand when sampling ground water wells (reference SOPs SA-6.1 and SA-7.1):

- Sample packaging and shipping equipment - Coolers for sample shipping and cooling, chemical preservatives, appropriate sampling containers and filler, ice, labels and chain-of-custody documents.
- Field tools and instrumentation - Thermometer, pH paper/meter, camera and film (if appropriate), appropriate keys (for locked wells), engineer's rule, water level indicator, specific conductivity meter, and turbidity meter (as applicable).
- Pumps
  - Shallow-well pumps: Centrifugal, pitcher, suction, or peristaltic pumps with droplines, air-lift apparatus (compressor and tubing) where applicable.
  - Deep-well pumps: Submersible pump and electrical power-generating unit, or air-lift apparatus where applicable.
- Other sampling equipment - Bailers and inert line with tripod-pulley assembly (if necessary). Bailers or submersible centrifugal pumps shall be used to obtain samples for volatile organics from shallow and deep groundwater wells.
- Pails - Plastic, graduated.
- Decontamination solutions - Deionized water, laboratory detergents, 10% nitric acid solution (as required), and analytical-grade solvents (e.g., methanol, acetone, hexane), as required.

Ideally, sample withdrawal equipment shall be completely inert, economical, easily cleaned, cleaned prior to use, reusable, able to operate at remote sites in the absence of power sources, and capable of delivering variable rates for well flushing and sample collection.



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### 5.3 Calculations of Well Volume

To insure that the proper volume of water has been removed from the well prior to sampling it is first necessary to know the volume of standing water in the well pipe. This volume can be easily calculated by the following method. Calculations shall be entered in the site logbook or field notebook or on a sample log sheet form (see SOP SA-6.3):

- Obtain all available information on well construction (location, casing, screens, etc.).
- Determine well or casing diameter.
- Measure and record static water level (depth below ground level or top of casing reference point).
- Determine depth of well by sounding using a clean, decontaminated, weighted tape measure.
- Calculate number of linear feet of static water (total depth or length of well pipe minus the depth to static water level).

- Calculate one static well volume in gallons  $V = (0.163)(T)(r^2)$

where:  $V$  = Static volume of well in gallons.  
 $T$  = Thickness of water table in the well measured in feet (i.e., linear feet of static water).  
 $r$  = Inside radius of well casing in inches.  
 $0.163$  = A constant conversion factor which compensates for the conversion of the casing radius from inches to feet, the conversion of cubic feet to gallons, and pi.

- Per evacuation volumes discussed above, determine the minimum amount to be evacuated before sampling.

### 5.4 Evacuation of Static Water (Purging)

#### 5.4.1 General

The amount of purging a well shall receive prior to sample collection will depend on the intent of the monitoring program and the hydrogeologic conditions. Programs to determine overall quality of water resources may require long pumping periods to obtain a sample that is representative of a large volume of that aquifer. The pumped volume may be specified prior to sampling so that the sample can be a composite of a known volume of the aquifer. Alternately the well can be pumped until the parameters such as temperature, electrical conductance, pH, and turbidity (as applicable), have stabilized. Onsite measurements of these parameters shall be recorded in the site logbook, field notebook, or on standardized data sheets.



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#### 5.4.2 Evacuation Devices

The following discussion is limited to those devices commonly used at hazardous waste sites. Attachment A provides guidance on the proper evacuation device to use for given sampling situations. Note that all of these techniques involve equipment which is portable and readily available.

##### Bailers

Bailers are the simplest evacuation devices used and have many advantages. They generally consist of a length of pipe with a sealed bottom (bucket-type bailer) or, as is more useful and favored, with a ball check-valve at the bottom. An inert line is used to lower the bailer and retrieve the sample.

Advantages of bailers include:

- Few limitations on size and materials used for bailers.
- No external power source needed.
- Bailers are inexpensive, and can be dedicated and hung in a well to reduce the chances of cross-contamination.
- There is minimal outgassing of volatile organics while the sample is in the bailer.
- Bailers are relatively easy to decontaminate.

Limitations on the use of bailers include the following:

- It is time consuming to remove stagnant water using a bailer.
- Transfer of sample may cause aeration.
- Use of bailers is physically demanding, especially in warm temperatures at protection levels above Level D.

##### Suction Pumps

There are many different types of inexpensive suction pumps including centrifugal, diaphragm, peristaltic, and pitcher pumps. Centrifugal and diaphragm pumps can be used for well evacuation at a fast pumping rate and for sampling at a low pumping rate. The peristaltic pump is a low volume pump that uses rollers to squeeze a flexible tubing, thereby creating suction. This tubing can be dedicated to a well to prevent cross contamination. The pitcher pump is a common farm hand-pump.

These pumps are all portable, inexpensive and readily available. However, because they are based on suction, their use is restricted to areas with water levels within 20 to 25 feet of the ground surface. A significant limitation is that the vacuum created by these pumps can cause significant loss of dissolved gases and volatile organics.

##### Air-Lift Samplers

This group of pump samplers uses gas pressure either in the annulus of the well or in a venturi to force the water up a sampling tube. These pumps are also relatively inexpensive. Air (or gas)-lift samplers are more suitable for well development than for sampling because the samples may be aerated, leading to pH changes and subsequent trace metal precipitation, or loss of volatile organics.



### Submersible Pumps

Submersible pumps take in water and push the sample up a sample tube to the surface. The power sources for these samplers may be compressed gas or electricity. The operation principles vary and the displacement of the sample can be by an inflatable bladder, sliding piston, gas bubble, or impeller. Pumps are available for 2-inch-diameter wells and larger. These pumps can lift water from considerable depths (several hundred feet).

Limitations of this class of pumps include:

- They may have low delivery rates.
- Many models of these pumps are expensive.
- Compressed gas or electric power is needed.
- Sediment in water may cause clogging of the valves or eroding the impellers with some of these pumps.
- Decontamination of internal components can be difficult and time-consuming.

## 5.5 Onsite Water Quality Testing

This section describes the procedures and equipment required to measure the following parameters of an aqueous sample in the field:

- pH
- Specific Conductance
- Temperature
- Dissolved Oxygen (DO) Concentration
- Oxidation Reduction Potential
- Certain Dissolved Constituents Using Specific Ion Elements
- Turbidity

This section is applicable for use in an onsite groundwater quality monitoring program to be conducted at a hazardous or nonhazardous site. The procedures and equipment described are applicable to groundwater samples and are not, in general, subject to solution interferences from color, turbidity, and colloidal material or suspended matter.

This section provides general information for measuring the parameters listed above with instruments and techniques in common use. Since instruments from different manufacturers may vary, review of the manufacturer's literature pertaining to the use of a specific instrument is required before use.

### 5.5.1 Measurement of pH

#### 5.5.1.1 General

Measurement of pH is one of the most important and frequently used tests in water chemistry. Practically every phase of water supply and wastewater treatment such as acid-base neutralization, water softening, and corrosion control is pH dependent. Likewise, the pH of leachate can be correlated with other chemical analyses to determine the probable source of contamination. It is therefore important that reasonably accurate pH measurements be taken.



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Two methods are given for pH measurement: the pH meter and pH indicator paper. The indicator paper is used when only a rough estimate of the pH is required, and the pH meter when a more accurate measurement is needed. The response of a pH meter can be affected to a slight degree by high levels of colloidal or suspended solids, but the effect is usually small and generally of little significance. Consequently, specific methods to overcome this interference are not described. The response of pH paper is unaffected by solution interferences from color, turbidity, colloidal or suspended materials unless extremely high levels capable of coating or masking the paper are encountered. In such cases, use of a pH meter is recommended.

#### 5.5.1.2 Principles of Equipment Operation

Use of pH papers for pH measurement relies on a chemical reaction caused by the acidity or basicity of the solution created by the addition of the water sample reacting with the indicator compound on the paper. Various types of pH papers are available, including litmus (for general acidity or basicity determination) and specific pH range hydron paper.

Use of a pH meter relies on the same principle as other ion-specific electrodes. Measurement relies on establishment of a potential difference across a glass or other type of membrane in response to (in this instance, hydrogen) ion concentration across that membrane. The membrane is conductive to ionic species and, in combination with a standard or reference electrode, a potential difference proportional to the ion concentration is generated and measured.

#### 5.5.1.3 Equipment

The following equipment is needed for taking pH measurements:

- Stand-alone 150 portable pH meter, or combination meter (e.g., Horiba U-10), or combination meter equipped with an in-line sample chamber.
- Combination electrode with polymer body to fit the above meter (alternately a pH electrode and a reference electrode can be used if the pH meter is equipped with suitable electrode inputs).
- Buffer solutions, as specified by the manufacturer.
- pH indicator paper, to cover the pH range 2 through 12.
- Manufacturer's operation manual.

#### 5.5.1.4 Measurement Techniques for Field Determination of pH

##### **pH Meter**

The following procedure is used for measuring pH with a pH meter (meter standardization is according to manufacturer's instructions):

- Inspect the instrument and batteries prior to initiation of the field effort.
- Check the integrity of the buffer solutions used for field calibration. Buffer solutions need to be changed often as a result of degradation upon exposure to the atmosphere.



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- Immerse the tip of the electrodes in water overnight. If this is not possible due to field conditions, immerse the electrode tip in water for at least an hour before use. The electrode tip may be immersed in a rubber or plastic sack containing buffer solution for field transport or storage. This is not applicable for all electrodes as some must be stored dry.
- If applicable, make sure all electrolyte solutions within the electrode(s) are at their proper levels and that no air bubbles are present within the electrode(s).
- Calibrate on a daily use basis following manufacturer's instructions. Record calibration data on an equipment calibration log sheet.
- Immerse the electrode(s) in the unknown solution, slowly stirring the probe until the pH stabilizes. Stabilization may take several seconds to minutes. If the pH continues to drift, the sample temperature may not be stable, a physical reaction (e.g., degassing) may be taking place in the sample, or the meter or electrode may be malfunctioning. This must be clearly noted in the logbook.
- Read and record the pH of the solution. pH shall be recorded to the nearest 0.1 pH unit. Also record the sample temperature.
- Rinse the electrode(s) with deionized water.
- Store the electrode(s) in an appropriate manner when not in use.

Any visual observation of conditions which may interfere with pH measurement, such as oily materials, or turbidity, shall be noted.

### pH Paper

Use of pH paper is very simple and requires no sample preparation, standardization, etc. pH paper is available in several ranges, including wide-range (indicating approximately pH 1 to 12), mid-range (approximately pH 0 to 6, 6 to 9, 8 to 14) and narrow-range (many available, with ranges as narrow as 1.5 pH units). The appropriate range of pH paper shall be selected. If the pH is unknown the investigation shall start with wide-range paper and proceed with successively narrower range paper until the sample pH is adequately determined.

## 5.5.2 Measurement of Specific Conductance

### 5.5.2.1 General

Conductance provides a measure of dissolved ionic species in water and can be used to identify the direction and extent of migration of contaminants in groundwater or surface water. It can also be used as a measure of subsurface biodegradation or to indicate alternate sources of groundwater contamination.

Conductivity is a numerical expression of the ability of a water sample to carry an electric current. This value depends on the total concentration of the ionized substances dissolved in the water and the temperature at which the measurement is made. The mobility of each of the various dissolved ions, their valences, and their actual and relative concentrations affect conductivity.



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It is important to obtain a specific conductance measurement soon after taking a sample, since temperature changes, precipitation reactions, and absorption of carbon dioxide from the air all affect the specific conductance.

#### 5.5.2.2 Principles of Equipment Operation

An aqueous system containing ions will conduct an electric current. In a direct-current field, the positive ions migrate toward the negative electrode, while the negatively charged ions migrate toward the positive electrode. Most inorganic acids, bases and salts (such as hydrochloric acid, sodium carbonate, or sodium chloride, respectively) are relatively good conductors. Conversely, organic compounds such as sucrose or benzene, which do not disassociate in aqueous solution, conduct a current very poorly, if at all.

A conductance cell and a Wheatstone Bridge (for the measurement of potential difference) may be used for measurement of electrical resistance. The ratio of current applied to voltage across the cell may also be used as a measure of conductance. The core element of the apparatus is the conductivity cell containing the solution of interest. Depending on ionic strength of the aqueous solution to be tested, a potential difference is developed across the cell which can be converted directly or indirectly (depending on instrument type) to a measurement of specific conductance.

#### 5.5.2.3 Equipment

The following equipment is needed for taking specific conductance (SC) measurements:

- Stand alone portable conductivity meter, or combination meter (e.g., Horiba U-10), or combination meter equipped with an in-line sample chamber.
- Calibration solution, as specified by the manufacturer.
- Manufacturer's operation manual.

A variety of conductivity meters are available which may also be used to monitor salinity and temperatures. Probe types and cable lengths vary, so equipment must be obtained to meet the specific requirement of the sampling program.

#### 5.5.2.4 Measurement Techniques for Specific Conductance

The steps involved in taking specific conductance measurements are listed below (standardization is according to manufacturer's instructions):

- Check batteries and calibrate instrument before going into the field.
- Calibrate on a daily use basis, according to the manufacturer's instructions and record all pertinent information on an equipment calibration log sheet. Potassium chloride solutions with a SC closest to the values expected in the field shall be used for calibration. Attachment B provides guidance in this regard.
- Rinse the cell with one or more portions of the sample to be tested or with deionized water.



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- Immerse the electrode in the sample and measure the conductivity. Adjust the temperature setting to the sample temperature (if applicable).
- Read and record the results in a field logbook or sample log sheet.
- Rinse the electrode with deionized water.

If the specific conductance measurements become erratic, recalibrate the instrument and see the manufacturer's instructions for details.

### 5.5.3 Measurement of Temperature

#### 5.5.3.1 General

In combination with other parameters, temperature can be a useful indicator of the likelihood of biological action in a water sample. It can also be used to trace the flow direction of contaminated groundwater. Temperature measurements shall be taken in-situ, or as quickly as possible in the field. Collected water samples may rapidly equilibrate with the temperature of their surroundings.

#### 5.5.3.2 Equipment

Temperature measurements may be taken with alcohol-toluene, mercury filled or dial-type thermometers. In addition, various meters such as specific conductance or dissolved oxygen meters, which have temperature measurement capabilities, may also be used. Using such instrumentation along with suitable probes and cables, in-situ measurements of temperature at great depths can be performed.

#### 5.5.3.3 Measurement Techniques for Water Temperature

If a thermometer is used to determine the temperature for a water sample:

- Immerse the thermometer in the sample until temperature equilibrium is obtained (1-3 minutes). To avoid the possibility of cross-contamination, the thermometer shall not be inserted into samples which will undergo subsequent chemical analysis.
- Record values in a field logbook or sample log sheet.

If a temperature meter or probe is used, the instrument shall be calibrated according to manufacturer's recommendations.

### 5.5.4 Measurement of Dissolved Oxygen Concentration

#### 5.5.4.1 General

Dissolved oxygen (DO) levels in natural water and wastewater depend on the physical, chemical and biochemical activities in the water body. Conversely, the growth of many aquatic organisms as well as the rate of corrosivity, are dependent on the dissolved oxygen concentration. Thus, analysis for dissolved oxygen is a key test in water pollution and waste treatment process control. If at all possible, DO measurements shall be taken in-situ, since concentration may show a large change in a short time if the sample is not adequately preserved.



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The monitoring method discussed herein is limited to the use of dissolved oxygen meters only. Chemical methods of analysis (i.e., Winkler methods) are available, but require more equipment and greater sample manipulation. Furthermore, DO meters, using a membrane electrode, are suitable for highly polluted waters, because the probe is completely submersible, and is not susceptible to interference caused by color, turbidity, colloidal material or suspended matter.

#### 5.5.4.2 Principles of Equipment Operation

Dissolved oxygen probes are normally electrochemical cells that have two solid metal electrodes of different nobility immersed in an electrolyte. The electrolyte is retained by an oxygen-permeable membrane. The metal of highest nobility (the cathode) is positioned at the membrane. When a suitable potential exists between the two metals, reduction of oxygen to hydroxide ion (OH) occurs at the cathode surface. An electrical current is developed that is directly proportional to the rate of arrival of oxygen molecules at the cathode.

Since the current produced in the probe is directly proportional to the rate of arrival of oxygen at the cathode, it is important that a fresh supply of sample always be in contact with the membrane. Otherwise, the oxygen in the aqueous layer along the membrane is quickly depleted and false low readings are obtained. It is therefore necessary to stir the sample (or the probe) constantly to maintain fresh solution near the membrane interface. Stirring, however, shall not be so vigorous that additional oxygen is introduced through the air-water interface at the sample surface. To avoid this possibility, some probes are equipped with stirrers to agitate the solution near the probe, while leaving the surface of the solution undisturbed.

Dissolved oxygen probes are relatively unaffected by interferences. Interferences that can occur are reactions with oxidizing gases (such as chlorine) or with gases such as hydrogen sulfide, which are not easily depolarized from the indicating electrode. If a gaseous interference is suspected, it shall be noted in the field log book and checked if possible. Temperature variations can also cause interference because probes exhibit temperature sensitivity. Automatic temperature compensation is normally provided by the manufacturer.

#### 5.5.4.3 Equipment

The following equipment is needed to measure dissolved oxygen concentration:

- Stand alone portable dissolved oxygen meter, or combination meter (e.g., Horiba U-10), or combination meter equipped with an in-line sample chamber.
- Sufficient cable to allow the probe to contact the sample.
- Manufacturer's operation manual.

#### 5.5.4.4 Measurement Techniques for Dissolved Oxygen Determination

Probes differ as to specifics of use. Follow the manufacturer's instructions to obtain an accurate reading. The following general steps shall be used to measure the dissolved oxygen concentration:

- The equipment shall be calibrated and have its batteries checked in the warehouse before going to the field.



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- The probe shall be conditioned in a water sample for as long a period as practical before use in the field. Long periods of dry storage followed by short periods of use in the field may result in inaccurate readings.
- The instrument shall be calibrated in the field according to manufacturer's recommendations or in a freshly air-saturated water sample of known temperature. Dissolved oxygen values for air-saturated water can be determined by consulting a table listing oxygen solubilities as a function of temperature and salinity (see Attachment C).
- Record all pertinent information on an equipment calibration sheet.
- Rinse the probe with deionized water.
- Immerse the probe in the sample. Be sure to provide for sufficient flow past the membrane by stirring the sample. Probes without stirrers placed in wells can be moved up and down.
- Record the dissolved oxygen content and temperature of the sample in a field logbook or sample log sheet.
- Rinse the probe with deionized water.
- Recalibrate the probe when the membrane is replaced, or as needed. Follow the manufacturer's instructions.

Note that in-situ placement of the probe is preferable, since sample handling is not involved. This however, may not always be practical. Be sure to record whether the liquid was analyzed in-situ, or if a sample was taken.

Special care shall be taken during sample collection to avoid turbulence which can lead to increased oxygen solubilization and positive test interferences.

### 5.5.5 Measurement of Oxidation-Reduction Potential

#### 5.5.5.1 General

The oxidation-reduction potential (ORP) provides a measure of the tendency of organic or inorganic compounds to exist in an oxidized state. The ORP parameter therefore provides evidence of the likelihood of anaerobic degradation of biodegradable organics or the ratio of activities of oxidized to reduced species in the sample.

#### 5.5.5.2 Principles of Equipment Operation

When an inert metal electrode, such as platinum, is immersed in a solution, a potential is developed at that electrode depending on the ions present in the solution. If a reference electrode is placed in the same solution, an ORP electrode pair is established. This electrode pair allows the potential difference between the two electrodes to be measured and is dependent on the concentration of the ions in solution. By this measurement, the ability to oxidize or reduce species in solution may be determined. Supplemental measurements, such as dissolved oxygen, may be correlated with ORP to provide a knowledge of the quality of the solution, water, or wastewater.



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#### 5.5.5.3 Equipment

The following equipment is needed for measuring the oxidation-reduction potential of a solution:

- Portable pH meter or equivalent, with a millivolt scale.
- Platinum electrode to fit above pH meter.
- Reference electrode such as a calomel, silver-silver chloride, or equivalent.
- Reference solution as specified by the manufacturer.
- Manufacturer's operation manual.

#### 5.5.5.4 Measurement Techniques for Oxidation-Reduction Potential

The following procedure is used for measuring oxidation-reduction potential:

- The equipment shall be calibrated and have its batteries checked before going to the field.
- Check that the platinum probe is clean and that the platinum bond or tip is unoxidized. If dirty, polish with emery paper or, if necessary, clean the electrode using aqua regia, nitric acid, or chromic acid, in accordance with manufacturer's instructions.
- Thoroughly rinse the electrode with deionized water.
- Verify the sensitivity of the electrodes by noting the change in millivolt reading when the pH of the test solution is altered. The ORP will increase when the pH of the test solution decreases and the ORP will decrease if the test solution pH is increased. Place the sample in a clean container and agitate the sample. Insert the electrodes and note the ORP drops sharply when the caustic is added (i.e., pH is raised) thus indicating the electrodes are sensitive and operating properly. If the ORP increases sharply when the caustic is added, the polarity is reversed and must be corrected in accordance with the manufacturer's instructions. If the ORP does not respond as above when the caustic is added, the electrodes shall be cleaned and the above procedure repeated.
- After the assembly has been checked for sensitivity, wash the electrodes with three changes of water or by means of a flowing stream of deionized water from a wash bottle. Place the sample in a clean container and insert the electrodes. Set temperature compensator throughout the measurement period. Read the millivolt potential of the solution, allowing sufficient time for the system to stabilize and reach temperature equilibrium. Measure successive portions of the sample until readings on two successive portions differ by no more than 10 mV. A system that is very slow to stabilize properly will not yield a meaningful ORP. Record all results in a field logbook or sample logsheet, including ORP (to nearest 10 mV), sample temperature and pH at the time of measurement.

#### 5.5.6 Measurement of Turbidity

##### 5.5.6.1 General

Turbidity in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and microscopic organisms, including plankton. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line through the sample.



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It is important to obtain a turbidity reading immediately after taking a sample, since irreversible changes in turbidity may occur if the sample is stored too long.

#### 5.5.6.2 Principles of Equipment Operation

Turbidity is measured by the Nephelometric Method. This method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the scattered light intensity, the higher the turbidity.

Formazin polymer is used as the reference turbidity standard suspension because of its ease of preparation combined with a higher reproducibility of its light-scattering properties than clay or turbid natural water. The turbidity of a specified concentration of formazin suspension is defined as 40 nephelometric units. This same suspension has an approximate turbidity of 40 Jackson units when measured on the candle turbidimeter. Therefore, nephelometric turbidity units (NTU) based on the formazin preparation will approximate units derived from the candle turbidimeter but will not be identical to them.

#### 5.5.6.3 Equipment

The following equipment is needed for turbidity measurement:

- Stand alone portable turbidity meter, or combination meter (e.g., Horiba U-10), or combination meter equipped with an in-line sample chamber.
- Calibration solution, as specified by the manufacturer.
- Manufacturer's operation manual.

#### 5.5.6.4 Measurements Techniques for Specific Conductance

The steps involved in taking turbidity measurements are listed below (standardization is according to manufacturer's instructions):

- Check batteries and calibrate instrument before going into the field.
- Check the expiration date (etc.) of the solutions used for field calibration.
- Calibrate on a daily use basis, according to the manufacturer's instructions and record all pertinent information on an equipment calibration log sheet.
- Rinse the cell with one or more portions of the sample to be tested or with deionized water.
- Immerse the probe in the sample and measure the turbidity. The reading must be taken immediately as suspended solids will settle over time resulting in a lower, inaccurate turbidity reading.



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- Read and record the results in a field logbook or sample log sheet. Include a physical description of the sample, including color, qualitative estimate of turbidity, etc.
- Rinse the electrode with deionized water.

## 5.6 Sampling

### 5.6.1 Sampling Plan

The sampling approach consisting of the following, shall be developed as part of the project plan documents which are approved prior to beginning work in the field:

- Background and objectives of sampling.
- Brief description of area and waste characterization.
- Identification of sampling locations, with map or sketch, and applicable well construction data (well size, depth, screened interval, reference elevation).
- Intended number, sequence volumes, and types of samples. If the relative degrees of contamination between wells is unknown or insignificant, a sampling sequence which facilitates sampling logistics may be followed. Where some wells are known or strongly suspected of being highly contaminated, these shall be sampled last to reduce the risk of cross-contamination between wells as a result of the sampling procedures.
- Sample preservation requirements.
- Work schedule.
- List of team members.
- List of observers and contacts.
- Other information, such as the necessity for a warrant or permission of entry, requirement for split samples, access problems, location of keys, etc.

### 5.6.2 Sampling Methods

The collection of a groundwater sample consists of the following steps:

1. The site Health & Safety Officer (or designee) will first open the well cap and use volatile organic detection equipment (PID or FID) on the escaping gases at the well head to determine the need for respiratory protection.
2. When proper respiratory protection has been donned, sound the well for total depth and water level (using clean equipment) and record these data on a groundwater sampling log sheet (see SOP SA-6.3); then calculate the fluid volume in the well pipe (as previously described in this SOP).
3. Calculate well volume to be removed as stated in Section 5.3.



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4. Select the appropriate purging equipment (see Attachment A). If an electric submersible pump with packer is chosen, go to Step 10.
5. Lower the purging equipment or intake into the well to a short distance below the water level and begin water removal. Collect the purged water and dispose of it in an acceptable manner (as applicable). Lower the purging device, as required, to maintain submergence.
6. Measure the rate of discharge frequently. A graduated bucket and stopwatch are most commonly used; other techniques include use of pipe trajectory methods, weir boxes or flow meters.
7. Observe the peristaltic pump intake for degassing "bubbles." If bubbles are abundant and the intake is fully submerged, this pump is not suitable for collecting samples for volatile organics. Never collect volatile organics samples using a vacuum pump.
8. Purge a minimum of three to five casing volumes before sampling. In low-permeability strata (i.e., if the well is pumped to dryness), one volume will suffice. Purged water shall be collected in a designated container and disposed in an acceptable manner.
9. If sampling using a pump, lower the pump intake to midscreen (or the middle of the open section in uncased wells) and collect the sample. If sampling with a bailer, lower the bailer to the sampling level before filling.
10. (For pump and packer assembly only). Lower the assembly into the well so that the packer is positioned just above the screen or open section. Inflate the packer. Purge a volume equal to at least twice the screened interval (or unscreened open section volume below the packer) before sampling. Packers shall always be tested in a casing section above ground to determine proper inflation pressures for good sealing.
11. In the event that recovery time of the well is very slow (e.g., 24 hours or greater), sample collection can be delayed until the following day. If the well has been purged early in the morning, sufficient water may be standing in the well by the day's end to permit sample collection. If the well is incapable of producing a sufficient volume of sample at any time, take the largest quantity available and record this occurrence in the site logbook.
12. Fill sample containers (preserve and label as described in SOP SA-6.1).
13. Replace the well cap and lock as appropriate. Make sure the well is readily identifiable as the source of the samples.
14. Process sample containers as described in SOP SA-6.1.
15. Decontaminate equipment as described in SOP SA-7.1.

## **5.7 Low Flow Purging and Sampling**

### **5.7.1 Scope & Application**

Low flow purging and sampling techniques are sometimes required for groundwater sampling activities. The purpose of low flow purging and sampling is to collect groundwater samples that contain



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"representative" amounts of mobile organic and inorganic constituents in the vicinity of the selected open well interval, at near natural flow conditions. The minimum stress procedure emphasizes negligible water level drawdown and low pumping rates in order to collect samples with minimal alterations in water chemistry. This procedure is designed primarily to be used in wells with a casing diameter of 2 inches or more and a saturated screen, or open interval, length of ten feet or less. Samples obtained are suitable for analyses of common types of groundwater contaminants (volatile and semi-volatile organic compounds, pesticides, PCBs, metals and other inorganic ions [cyanide, chloride, sulfate, etc.]). This procedure is not designed to collect non-aqueous phase liquids samples from wells containing light or dense non-aqueous phase liquids (LNAPLs or DNAPLs), using the low flow pumps.

The procedure is flexible for various well construction types and groundwater yields. The goal of the procedure is to obtain a turbidity level of less than 5 NTU and to achieve a water level drawdown of less than 0.3 feet during purging and sampling. If these goals cannot be achieved, sample collection can take place provided the remaining criteria in this procedure are met.

#### 5.7.2 Equipment

The following equipment is required (as applicable) for low flow purging and sampling:

- Adjustable rate, submersible pump (e.g., centrifugal or bladder pump constructed of stainless steel or Teflon). Peristaltic pumps may be used only for inorganic sample collection.
- Disposable clear plastic bottom filling bailers may be used to check for and obtain samples of LNAPLs or DNAPLs.
- Tubing - Teflon, Teflon lined polyethylene, polyethylene, PVC, tygon steel tubing can be used to collect samples for analysis, depending on the analyses to be performed and regulatory requirements.
- Water level measuring device, 0.01 foot accuracy, (electronic devices are preferred for tracking water level drawdown during all pumping operations).
- Flow measurement supplies.
- Interface probe, if needed.
- Power source (generator, nitrogen tank, etc.). If a gasoline generator is used, it must be located downwind and at a safe distance from the well so that the exhaust fumes do not contaminate the samples.
- Indicator parameter monitoring instruments - pH, turbidity, specific conductance, and temperature. Use of a flow-through cell is recommended. Optional Indicators - eH and dissolved oxygen, flow-through cell is required. Standards to perform field calibration of instruments.
- Decontamination supplies.
- Logbook(s), and other forms (e.g., well purging forms).
- Sample Bottles.



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- Sample preservation supplies (as required by the analytical methods).
- Sample tags or labels.
- Well construction data, location map, field data from last sampling event.
- Field Sampling Plan.
- PID or FID instrument for measuring VOCs (volatile organic compounds).

### 5.7.3 Purging and Sampling Procedure

Use a submersible pump to purge and sample monitoring wells which have a 2.0 inch or greater well casing diameter.

Measure and record the water level immediately prior to placing the pump in the well.

Lower pump, safety cable, tubing and electrical lines slowly into the well so that the pump intake is located at the center of the saturated screen length of the well. If possible keep the pump intake at least two feet above the bottom of the well, to minimize mobilization of sediment that may be present in the bottom of the well. Collection of turbid free water samples may be difficult if there is three feet or less of standing water in the well.

When starting the pump, slowly increase the pump speed until a discharge occurs. Check water level. Adjust pump speed to maintain little or no water level drawdown. The target drawdown should be less than 0.3 feet and it should stabilize. If the target of less than 0.3 feet cannot be achieved or maintained, the sampling is acceptable if remaining criteria in the procedure are met. Subsequent sampling rounds will probably have intake settings and extraction rates that are comparable to those used in the initial sampling rounds.

Monitor water level and pumping rate every three to five minutes (or as appropriate) during purging. Record pumping rate adjustments and depths to water. Pumping rates should, as needed, be reduced to the minimum capabilities of the pump (e.g., 0.1-0.2 l/min) to ensure stabilization of indicator parameters. Adjustments are best made in the first fifteen minutes of pumping in order to help minimize purging time. During initial pump start-up, drawdown may exceed the 0.3 feet target and then recover as pump flow adjustments are made (minimum purge volume calculations should utilize stabilized drawdown values, not the initial drawdown). If the recharge rate of the well is less than minimum capability of the pump do not allow the water level to fall to the intake level (if the static water level is above the screen, avoid lowering the water level into the screen). Shut off the pump if either of the above is about to occur and allow the water level to recover. Repeat the process until field indicator parameters stabilize and the minimum purge volume is removed. The minimum purge volume with negligible drawdown (0.3 feet or less) is two saturated screen length volumes. In situations where the drawdown is greater than 0.3 feet and has stabilized, the minimum purge volume is two times the saturated screen volume plus the stabilized drawdown volume. After the minimum purge volume is attained (and field parameters have stabilized) begin sampling. For low yields wells, commence sampling as soon as the well has recovered sufficiently to collect the appropriate volume for all anticipated samples.

During well purging, monitor field indicator parameters (turbidity, temperature, specific conductance, pH, etc.) every three to five minutes (or as appropriate). Purging is complete and sampling may begin when



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all field indicator parameters have stabilized (variations in values are within ten percent of each other, pH +/- 0.2 units, for three consecutive readings taken at three to five minute intervals). If the parameters have stabilized, but turbidity remains above 5 NTU goal, decrease pump flow rate, and continue measurement of parameters every three to five minutes. If pumping rate cannot be decreased any further and stabilized turbidity values remain above 5 NTU goal record this information. Measurements of field parameters should be obtained (as per Section 5.5) and recorded.

VOC samples are preferably collected first and directly into pre-preserved sample containers. Fill all sample containers by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

If the water column in the pump tubing collapses (water does not completely fill the tubing) before exiting the tubing, use one of the following procedures to collect VOC samples: (1) Collect the non-VOCs samples first, then increase the flow rate incrementally until the water column completely fills the tubing, collect the sample and record the new flow rate; (2) reduce the diameter of the existing tubing until the water column fills the tubing either by adding a connector (Teflon or stainless steel), or clamp which should reduce the flow rate by constricting the end of the tubing; (3) insert a narrow diameter Teflon tube into the pump's tubing so that the end of the tubing is in the water column and the other end of the tubing protrudes beyond the pump's tubing, collect sample from the narrow diameter tubing.

Prepare samples for shipping as per SOP SA-6.1.

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## ATTACHMENT A

### PURGING EQUIPMENT SELECTION

Diameter Casing		Bailer	Peristaltic Pump	Vacuum Pump	Air-lift	Diaphragm "Trash" Pump	Submersible Diaphragm Pump	Submersible Electric Pump	Submersible Electric Pump w/Packer
1.25-Inch	Water level < 25 feet		X	X	X	X			
	Water Level > 25 feet				X				
2-Inch	Water level < 25 feet	X	X	X	X	X	X		
	Water Level > 25 feet	X			X		X		
4-Inch	Water level < 25 feet	X	X	X	X	X	X	X	X
	Water Level > 25 feet	X			X		X	X	X
6-Inch	Water level < 25 feet				X	X		X	X
	Water Level > 25 feet				X			X	X
8-Inch	Water level < 25 feet				X	X		X	X
	Water Level > 25 feet				X			X	X



GROUNDWATER SAMPLE  
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PURGING EQUIPMENT SELECTION  
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Manufacturer	Model Name/Number	Principle of Operation	Maximum Outside Diameter/Length (Inches)	Construction Materials (w/Lines and Tubing)	Lift Range (ft)	Delivery Rates or Volumes	1982 Price (Dollars)	Comments
BarCad Systems, Inc.	BarCad Sampler	Dedicated; gas drive (positive displacement)	1.5/16	PE, brass, nylon, aluminum oxide	0-150 with std. tubing	1 liter for each 10-15 feet of submergence	\$220-350	Requires compressed gas; custom sizes and materials available; acts as piezometer.
Cole-Parmer Inst. Co.	Master Flex 7570 Portable Sampling Pump	Portable; peristaltic (suction)	< 1.0/NA	(not submersible) Tygon®, silicone Viton®	0-30	670 mL/min with 7015-20 pump head	\$500-600	AC/DC; variable speed control available; other models may have different flow rates.
ECO Pump Corp.	SAMPLifier	Portable; venturi	< 1.5 or < 2.0/NA	PP, PE, PVC, SS, Teflon®, Tefzel®	0-100	0-500 mL/min depending on lift	\$400-700	AC, DC, or gasoline-driven motors available; must be primed.
Geltek Corp.	Bailer 219-4	Portable; grab (positive displacement)	1.66/38	Teflon®	No limit	1,075 mL	\$120-135	Other sizes available.
GeoEngineering, Inc.	GEO-MONITOR	Dedicated; gas drive (positive displacement)	1.5/16	PE, PP, PVC, Viton®	Probably 0-150	Approximately 1 liter for each 10 feet of submergence	\$185	Acts as piezometer; requires compressed gas.
Industrial and Environmental Analysts, Inc. (IEA)	Aquarius	Portable; bladder (positive displacement)	1.75/43	SS, Teflon®, Viton®	0-250	0-2,800 mL/min	\$1,500-3,000	Requires compressed gas; other models available; AC, DC, manual operation possible.
IEA	Syringe Sampler	Portable; grab (positive displacement)	1.75/43	SS, Teflon®	No limit	850 mL sample volume	\$1,100	Requires vacuum and/or pressure from hand pump.
Instrument Specalties Co. (ISCO)	Model 2600 Well Sampler	Portable; bladder (positive displacement)	1.75/50	PC, silicone, Teflon®, PP, PE, Detrin®, acetal	0-150	0-7,500 mL/min	\$990	Requires compressed gas (40 psi minimum).
Keck Geophysical Instruments, Inc.	SP-81 Submersible Sampling Pump	Portable; helical rotor (positive displacement)	1.75/25	SS, Teflon®, PP, EPDM, Viton®	0-160	0-4,500 mL/min	\$3,500	DC operated.
Leonard Mold and Die Works, Inc.	GeoFilter Small Diameter Well Pump (#0500)	Portable; bladder (positive displacement)	1.75/38	SS, Teflon®, PC, Neoprene®	0-400	0-3,500 mL/min	\$1,400-1,500	Requires compressed gas (55 psi minimum); pneumatic or AC/DC control module.
Oil Recovery Systems, Inc.	Surface Sampler	Portable; grab (positive displacement)	1.75/12	acrylic, Detrin®	No limit	Approximately 250 mL	\$125-160	Other materials and models available; for measuring thickness of "floating" contaminants.
Q.E.D. Environmental Systems, Inc.	Well Wizard® Monitoring System (P-100)	Dedicated; bladder (positive displacement)	1.66/36	PVC	0-230	0-2,000 mL/min	\$300-400	Requires compressed gas; piezometric level indicator; other materials available.



**ATTACHMENT A**  
**PURGING EQUIPMENT SELECTION**  
**PAGE 3**

Manufacturer	Model Name/Number	Principle of Operation	Maximum Outside Diameter/Length (Inches)	Construction Materials (w/Lines and Tubing)	Lift Range (ft)	Delivery Rates or Volumes	1982 Price (Dollars)	Comments
Randolph Austin Co.	Model 500 Vari-Flow Pump	Portable; peristaltic (suction)	<0.5/NA	(Not submersible) Rubber, Tygon®, or Neoprene®	0-30	See comments	\$1,200-1,300	Flow rate dependent on motor and tubing selected; AC operated; other models available.
Robert Bennett Co.	Model 180	Portable; piston (positive displacement)	1.8/22	SS, Teflon®, Delrin® PP, Viton®, acrylic, PE	0-500	0-1,800 mL/min	\$2,600-2,700	Requires compressed gas; water level indicator and flow meter; custom models available.
Slope Indicator Co. (SINCO)	Model 514124 Pneumatic Water Sampler	Portable; gas drive (positive displacement)	1.9/18	PVC, nylon	0-1,100	250 mL/flushing cycle	\$250-350	Requires compressed gas; SS available; piezometer model available; dedicated model available.
Solinst Canada Ltd.	5W Water Sampler	Portable; grab (positive displacement)	1.9/27	PVC, brass, nylon, Neoprene®	0-330	500 mL	\$1,300-1,800	Requires compressed gas; custom models available.
TIMCO Mfg. Co., Inc.	Std. Bailer	Portable; grab (positive displacement)	1.66/Custom	PVC, PP	No limit	250 mL/ft of bailer	\$20-60	Other sizes, materials, models available; optional bottom-emptying device available; no solvents used.
TIMCO	Air or Gas Lift Sampler	Portable; gas drive (positive displacement)	1.66/30	PVC, Tygon®, Teflon®	0-150	350 mL/flushing cycle	\$100-200	Requires compressed gas; other sizes, materials, models available; no solvents used.
Tote Devices Co.	Sampling Pump	Portable; bladder (positive displacement)	1.38/48	SS, silicone, Delrin®, Tygon®	0-125	0-4,000 mL/min	\$800-1,000	Compressed gas required; DC control module; custom built.

**Construction Material Abbreviations:**

PE Polyethylene  
 PP Polypropylene  
 PVC Polyvinyl chloride  
 SS Stainless steel  
 PC Polycarbonate  
 EPDM Ethylene-propylene diene (synthetic rubber)

**Other Abbreviations:**

NA Not applicable  
 AC Alternating current  
 DC Direct current

**NOTE:** Other manufacturers market pumping devices which could be used for groundwater sampling, though not expressly designed for this purpose. The list is not meant to be all-inclusive and listing does not constitute endorsement for use. Information in the table is from sales literature and/or personal communication. No skimmer, scavenger-type, or high-capacity pumps are included.

Source: Barcelona et al., 1983.

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# ATTACHMENT B

## SPECIFIC CONDUCTANCE OF 1 MOLAR KCl AT VARIOUS TEMPERATURES<sup>1</sup>

Temperature (°C)	Specific Conductance (umhos/cm)
15	1,147
16	1,173
17	1,199
18	1,225
19	1,251
20	1,278
21	1,305
22	1,332
23	1,359
24	1,368
25	1,413
26	1,441
27	1,468
28	1,496
29	1,524
30	1,552

<sup>1</sup> Data derived from the International Critical  
Tables 1-3-8.



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### ATTACHMENT C

#### VARIATION OF DISSOLVED OXYGEN CONCENTRATION IN WATER AS A FUNCTION OF TEMPERATURE AND SALINITY

Temperature (°C)	Dissolved Oxygen (mg/L)					
	Chloride Concentration in Water					Difference/ 100 mg Chloride
	0	5,000	10,000	15,000	20,000	
0	14.6	13.8	13.0	12.1	11.3	0.017
1	14.2	13.4	12.6	11.8	11.0	0.016
2	13.8	13.1	12.3	11.5	10.8	0.015
3	13.5	12.7	12.0	11.2	10.5	0.015
4	13.1	12.4	11.7	11.0	10.3	0.014
5	12.8	12.1	11.4	10.7	10.0	0.014
6	12.5	11.8	11.1	10.5	9.8	0.014
7	12.2	11.5	10.9	10.2	9.6	0.013
8	11.9	11.2	10.6	10.0	9.4	0.013
9	11.6	11.0	10.4	9.8	9.2	0.012
10	11.3	10.7	10.1	9.6	9.0	0.012
11	11.1	10.5	9.9	9.4	8.8	0.011
12	10.8	10.3	9.7	9.2	8.6	0.011
13	10.6	10.1	9.5	9.0	8.5	0.011
14	10.4	9.9	9.3	8.8	8.3	0.010
15	10.2	9.7	9.1	8.6	8.1	0.010
16	10.0	9.5	9.0	8.5	8.0	0.010
17	9.7	9.3	8.8	8.3	7.8	0.010
18	9.5	9.1	8.6	8.2	7.7	0.009
19	9.4	8.9	8.5	8.0	7.6	0.009
20	9.2	8.7	8.3	7.9	7.4	0.009
21	9.0	8.6	8.1	7.7	7.3	0.009
22	8.8	8.4	8.0	7.6	7.1	0.008
23	8.7	8.3	7.9	7.4	7.0	0.008
24	8.5	8.1	7.7	7.3	6.9	0.008
25	8.4	8.0	7.6	7.2	6.7	0.008



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**ATTACHMENT C**  
**VARIATION OF DISSOLVED OXYGEN CONCENTRATION IN WATER**  
**AS A FUNCTION OF TEMPERATURE AND SALINITY**  
**PAGE TWO**

Temperature (°C)	Dissolved Oxygen (mg/L)					
	Chloride Concentration in Water					Difference/ 100 mg Chloride
	0	5,000	10,000	15,000	20,000	
26	8.2	7.8	7.4	7.0	6.6	0.008
27	8.1	7.7	7.3	6.9	6.5	0.008
28	7.9	7.5	7.1	6.8	6.4	0.008
29	7.8	7.4	7.0	6.6	6.3	0.008
30	7.6	7.3	6.9	6.5	6.1	0.008
31	7.5					
32	7.4					
33	7.3					
34	7.2					
35	7.1					
36	7.0					
37	6.9					
38	6.8					
39	6.7					
40	6.6					
41	6.5					
42	6.4					
43	6.3					
44	6.2					
45	6.1					
46	6.0					
47	5.9					
48	5.8					
49	5.7					
50	5.6					

Note: In a chloride solution, conductivity can be roughly related to chloride concentration (and therefore, used to correct measured D.O. concentration) using Attachment B.

















BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

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04/11/97

Revision

4

Applicability

B&R Environmental, NE

Prepared

Earth Sciences Department

Subject

SOIL SAMPLING

Approved

D. Senovich

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## 1.0 PURPOSE

This procedure discusses the methods used to collect surface, near surface, and subsurface soil samples. Additionally, it describes the method for sampling of test pits and trenches to determine subsurface soil and rock conditions, and recover small-volume or bulk samples.

## 2.0 SCOPE

This procedure is applicable to the collection of surface, near surface and subsurface soils for laboratory testing, which are exposed through hand digging, hand augering, drilling, or machine excavating at hazardous substance sites.

## 3.0 GLOSSARY

Composite Sample - A composite sample exists as a combination of more than one sample at various locations and/or depths and times, which is homogenized and treated as one sample. This type of sample is usually collected when determination of an average waste concentration for a specific area is required. Composite samples are not to be collected for volatile organics analysis.

Grab Sample - One sample collected at one location and at one specific time.

Non-Volatile Sample - A non-volatile sample includes all other chemical parameters (e.g., semivolatiles, pesticides/PCBs, metals, etc.) and those engineering parameters that do not require undisturbed soil for their analysis.

Hand Auger - A sampling device used to extract soil from the ground in a relatively undisturbed form.

Thin-Walled Tube Sampler - A thin-walled metal tube (also called a Shelby tube) used to recover relatively undisturbed soil samples. These tubes are available in various sizes, ranging from 2 to 5 inches outside diameter (OD) and from 18 to 54 inches in length.

Split-Barrel Sampler - A steel tube, split in half lengthwise, with the halves held together by threaded collars at either end of the tube. Also called a split-spoon sampler, this device can be driven into resistant materials using a drive weight mounted in the drilling string. A standard split-barrel sampler is typically available in two common lengths, providing either 20-inch or 26-inch longitudinal clearance for obtaining 18-inch or 24-inch-long samples, respectively. These split-barrel samplers commonly range in size from 2-inch OD to 3-1/2 inch OD. The larger sizes are commonly used when a larger volume of sample material is required.

Test Pit and Trench - Open, shallow excavations, typically rectangular (if a test pit) or longitudinal (if a trench), excavated to determine the shallow subsurface conditions for engineering, geological, and soil chemistry exploration and/or sampling purposes. These pits are excavated manually or by machine (e.g., backhoe, clamshell, trencher excavator, or bulldozer).

Confined Space - As stipulated in 29 CFR 1910.146, a confined space means a space that: 1) is large enough and so configured that an employee can bodily enter and perform assigned work; 2) has limited or restricted means for entry or exit (for example tanks, vessels, silos, storage bins, hoppers, vaults, and pits, and excavations are spaces that may have limited means of entry.); and 3) is not designed for continuous employee occupancy. Brown & Root Environmental considers all confined space as permit-required confined spaces.



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#### 4.0 RESPONSIBILITIES

Project Manager - The Project Manager is responsible for determining sampling objectives, as well as, the field procedures used in the collection of soil samples. Additionally, in consultation with other project personnel (geologist, hydrogeologist, etc.), the Project Manager establishes the need for test pits or trenches, and determines their approximate locations and dimensions.

Site Safety Officer (SSO) - The SSO (or a qualified designee) is responsible for providing the technical support necessary to implement the project Health and Safety Plan. This will include (but not be limited to) performing air quality monitoring during sampling, boring and excavation activities, and to ensure that workers and offsite (downwind) individuals are not exposed to hazardous levels of airborne contaminants. The SSO/designee may also be required to advise the FOL on other safety-related matters regarding boring, excavation and sampling, such as mitigative measures to address potential hazards from unstable trench walls, puncturing of drums or other hazardous objects, etc.

Field Operations Leader (FOL) - The FOL is responsible for finalizing the location of surface, near surface, and subsurface (hand and machine borings, test pits/trenches) soil samples. He/she is ultimately responsible for the sampling and backfilling of boreholes, test pits and trenches, and for adherence to OSHA regulations during these operations.

Project Geologist/Sampler - The project geologist/sampler is responsible for the proper acquisition of soil samples and the completion of all required paperwork (i.e., sample log sheets, field notebook, boring logs, test pit logs, container labels, custody seals, and chain-of-custody forms).

Competent Person - A Competent Person, as defined in 29 CFR 1929.650 of Subpart P - Excavations, means one who is capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.

#### 5.0 PROCEDURES

##### 5.1 Overview

Soil sampling is an important adjunct to groundwater monitoring. Sampling of the soil horizons above the groundwater table can detect contaminants before they have migrated into the water table, and can establish the amount of contamination sorbed on aquifer solids that have the potential of contributing to groundwater contamination.

Soil types can vary considerably on a hazardous waste site. These variations, along with vegetation, can effect the rate of contaminant migration through the soil. It is important, therefore, that a detailed record be maintained during the sampling operations, particularly noting the location, depth, and such characteristics as grain size, color, and odor. Subsurface conditions are often stable on a daily basis and may demonstrate only slight seasonal variation especially with respect to temperature, available oxygen and light penetration. Changes in any of these conditions can radically alter the rate of chemical reactions or the associated microbiological community, thus further altering specific site conditions. As a result, samples must be kept at their at-depth temperature or lower, protected from direct light, sealed tightly in approved glass containers and be analyzed as soon as possible.



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The physical properties of the soil, its grain size, cohesiveness, associated moisture, and such factors as depth to bedrock and water table, will limit the depth from which samples can be collected and the method required to collect them. Often this information on soil properties can be obtained from published soil surveys available through the U.S. Geological Surveys and other government or farm agencies. It is the intent of this procedure to present the most commonly employed soil sampling methods used at hazardous waste sites.

## **5.2 Soil Sample Collection**

**5.2.1 Procedure for Collecting Volatile Soil Samples** Volatile samples are only collected as grab samples and maintained and handled in as near an undisturbed state as possible. The sample is transferred directly into an approved glass container with a Teflon lined cap. The sample must be packed down as much as possible to reduce air space within the sample container to an absolute minimum. Also, a properly filled volatile organics sample container will have no head space.

## **5.2.2 Procedure for Collecting Non-Volatile Soil Samples**

Non-volatile soil samples may be collected as either grab or composite samples. The non-volatile soil sample is thoroughly mixed in a stainless steel or disposable, inert plastic tray, using a stainless steel trowel or other approved tool, then transferred into the appropriate sample container(s). Head space is permitted in a non-volatile soil sample container to allow for sample expansion.

## **5.2.3 Procedure for Collecting Undisturbed Soil Samples (ASTM D1587-83)**

When it is necessary to acquire undisturbed samples of soil for purposes of engineering parameter analysis (e.g., permeability), a thin-walled, seamless tube sampler (Shelby tube) will be employed. The following method will be used:

1. Remove all surface debris (e.g., vegetation, roots, twigs, etc.) from the specific sampling location and drill and clean out the borehole to the sampling depth, being careful to minimize the chance for disturbance of the material to be sampled. In saturated material, withdraw the drill bit slowly to prevent loosening of the soil around the borehole and to maintain the water level in the hole at or above groundwater level.
2. The use of bottom discharge bits or jetting through an open-tube sampler to clean out the borehole shall not be allowed. Use of any side-discharge bits is permitted.
3. A stationary piston-type sampler may be required to limit sample disturbance and aid in retaining the sample. Either the hydraulically operated or control rod activated-type of stationary piston sampler may be used. Prior to inserting the tube sampler into the borehole, check to ensure that the sampler head contains a check valve. The check valve is necessary to keep water in the rods from pushing the sample out the tube sampler during sample withdrawal and to maintain a suction within the tube to help retain the sample.
4. To minimize chemical reaction between the sample and the sampling tube, brass tubes may be required, especially if the tube is stored for an extended time prior to testing. While steel tubes coated with shellac are less expensive than brass, they're more reactive, and shall only be used when the sample will be tested within a few days after sampling or if chemical reaction is not anticipated. With the sampling tube resting on the bottom of the hole and the water level in the boring at groundwater level or above, push the tube into the soil by a



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continuous and rapid motion, without impacting or twisting. In no case shall the tube be pushed farther than the length provided for the soil sample. Allow about 3 inches in the tube for cuttings and sludge.

5. Upon removal of the sampling tube from the hole, measure the length of sample in the tube and also the length penetrated. Remove disturbed material in the upper end of the tube and measure the length of sample again. After removing at least an inch of soil from the lower end and after inserting an impervious disk, seal both ends of the tube with at least a 1/2-inch thickness of wax applied in a way that will prevent the wax from entering the sample. Clean filler must be placed in voids at either end of the tube prior to sealing with wax. Place plastic caps on the ends of the sample tube, tape the caps in place, and dip the ends in wax.
6. Affix label(s) to the tube as required and record sample number, depth, penetration, and recovery length on the label. Mark the "up" direction on the side of the tube with indelible ink, and mark the end of the sample. Complete Chain-of-Custody and other required forms (see SOP SA-6.3). Do not allow tubes to freeze, and store the samples vertically with the same orientation they had in the ground, (i.e., top of sample is up) in a cool place out of the sun at all times. Ship samples protected with suitable resilient packing material to reduce shock, vibration, and disturbance.

Thin-walled undisturbed tube samplers are restricted in their usage by the consistency of the soil to be sampled. Often, very loose and/or wet samples cannot be retrieved by the samplers, and soils with a consistency in excess of very stiff cannot be penetrated by the sampler. Devices such as Dennison or Pitcher core samplers can be used to obtain undisturbed samples of stiff soils. Using these devices normally increases sampling costs, and therefore their use shall be weighed against the need for acquiring an undisturbed sample.

### 5.3 Surface Soil Sampling

The simplest, most direct method of collecting surface soil samples (most commonly collected to a depth of 6 inches) for subsequent analysis is by use of a stainless steel trowel.

In general, the following equipment is necessary for obtaining surface soil samples:

- Stainless steel trowel.
- Real-time air monitoring instrument (e.g., PID, FID, etc.).
- Latex gloves.
- Required Personal Protective Equipment (PPE).
- Required paperwork.
- Required decontamination equipment.
- Required sample container(s).
- Wooden stakes or pin flags.
- Sealable polyethylene bags (i.e., Ziploc baggies).
- Heavy duty cooler.
- Ice (if required) double-bagged in sealable polyethylene bags.
- Chain-of-custody records and custody seals.

When acquiring surface soil samples, the following procedure shall be used:

1. Carefully remove vegetation, roots, twigs, litter, etc., to expose an adequate soil surface area to accommodate sample volume requirements.



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2. Using a decontaminated stainless steel trowel, follow the procedure cited in Section 5.2.1 for collecting a volatile soil sample.
3. Thoroughly mix (in-situ) a sufficient amount of soil to fill the remaining sample containers and transfer the sample into those containers utilizing the same stainless steel trowel employed above. Cap and securely tighten all sample containers.
4. Affix a sample label to each container. Be sure to fill out each label carefully and clearly, addressing all the categories described in SOP SA-6.3.
5. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.

**5.4      Near-Surface Soil Sampling**

Collection of samples from near the surface (depth of 6-18 inches) can be accomplished with tools such as shovels and stainless steel trowels.

The following equipment is necessary to collect near surface soil samples:

- Clean shovel.
- Plus the equipment listed under Section 5.3 of this procedure.

To obtain near-surface soil samples, the following protocol shall be observed:

1. With a clean shovel, make a series of vertical cuts to the depth required in the soil to form a square approximately 1 foot by 1 foot.
2. Lever out the formed plug and scrape the bottom of the freshly dug hole with a decontaminated stainless steel trowel to remove any loose soil.
3. Follow steps 2 through 5 listed under Section 5.3 of this procedure.

**5.5      Subsurface Soil Sampling With a Hand Auger**

A hand augering system generally consists of a variety of all stainless steel bucket bits (i.e., cylinders 6-1/2" long, and 2-3/4", 3-1/4", and 4" in diameter), a series of extension rods (available in 2', 3', 4' and 5' lengths), and a cross handle. A larger diameter bucket bit is commonly used to bore a hole to the desired sampling depth and then withdrawn. In turn, the larger diameter bit is replaced with a smaller diameter bit, lowered down the hole, and slowly turned into the soil at the completion depth (approximately 6"). The apparatus is then withdrawn and the soil sample collected.

The hand auger can be used in a wide variety of soil conditions. It can be used to sample soil both from the surface, or to depths in excess of 12 feet. However, the presence of rock layers and the collapse of the borehole normally contribute to its limiting factors.

To accomplish soil sampling using a hand augering system, the following equipment is required:

- Complete hand auger assembly (variety of bucket bit sizes).
- Stainless steel mixing bowls.
- Plus the equipment listed under Section 5.3 of this procedure.



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To obtain soil samples using a hand auger, the following procedure shall be followed:

1. Attach a properly decontaminated bucket bit to a clean extension rod and further attach the cross handle to the extension rod.
2. Clear the area to be sampled of any surface debris (vegetation, twigs, rocks, litter, etc.).
3. Begin augering (periodically removing accumulated soils from the bucket bit) and add additional rod extensions as necessary. Also, note (in a field notebook or on standardized data sheets) any changes in the color, texture or odor of the soil.
4. After reaching the desired depth, slowly and carefully withdraw the apparatus from the borehole.
5. Remove the soiled bucket bit from the rod extension and replace it with another properly decontaminated bucket bit. The bucket bit used for sampling is commonly smaller in diameter than the bucket bit employed to initiate the borehole.
6. Carefully lower the apparatus down the borehole. Care must be taken to avoid scraping the borehole sides.
7. Slowly turn the apparatus until the bucket bit is advanced approximately 6 inches.
8. Discard the top of the core (approximately 1"), which represents any loose material collected by the bucket bit before penetrating the sample material.
9. Fill volatile sample container(s), using a properly decontaminated stainless steel trowel, with sample material directly from the bucket bit. Refer to Section 5.2.1 of this procedure.
10. Utilizing the above trowel, remove the remaining sample material from the bucket bit and place into a properly decontaminated stainless steel mixing bowl and thoroughly homogenize the sample material prior to filling the remaining sample containers. Refer to Section 5.2.2 of this procedure.
11. Follow steps 4 and 5 listed under Section 5.3 of this procedure.

#### **5.6 Subsurface Soil Sampling With a Split-Barrel Sampler (ASTM D1586-84)**

Split-barrel (split-spoon) samplers consist of a heavy carbon steel or stainless steel sampling tube that can be split into two equal halves to reveal the soil sample (see Attachment A). A drive head is attached to the upper end of the tube and serves as a point of attachment for the drill rod. A removable tapered nosepiece/drive shoe attaches to the lower end of the tube and facilitates cutting. A basket-like sample retainer can be fitted to the lower end of the split tube to hold loose, dry soil samples in the tube when the sampler is removed from the drill hole. This split-barrel sampler is made to be attached to a drill rod and forced into the ground by means of a 140-lb. or larger casing driver.

Split-barrel samplers are used to collect soil samples from a wide variety of soil types and from depths greater than those attainable with other soil sampling equipment.

The following equipment is used for obtaining split-barrel samples:



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- Drilling equipment (provided by subcontractor).
- Split-barrel samplers (O.D. 2 inches, I.D. 1-3/8 inches, either 20 inches or 26 inches long); Larger O.D. samplers are available if a larger volume of sample is needed.
- Drive weight assembly, 140-lb. weight, driving head and guide permitting free fall of 30 inches.
- Stainless steel mixing bowls.
- Plus equipment listed under Section 5.3 of this procedure.

The following steps shall be followed to obtain split-barrel samples:

1. Remove the drive head and nosepiece, and open the sampler to reveal the soil sample. Immediately scan the sample core with a real-time air monitoring instrument (e.g., OVA, HNu, etc.). Carefully separate the soil core, with a decontaminated stainless steel knife or trowel, at about 6-inch intervals while scanning the center of the core for elevated readings. Also scan stained soil, soil lenses, and anomalies (if present), and record readings.
2. Collect the volatile sample from the center of the core where elevated readings occurred. If no elevated readings were encountered the sample material should still be collected from the core's center (this area represents the least disturbed area with minimal atmospheric contact). Refer to Section 5.2.1 of this procedure.
3. Using the same trowel, remove remaining sample material from the split-barrel sampler (except for the small portion of disturbed soil usually found at the top of the core sample) and place the soil into a decontaminated stainless steel mixing bowl. Thoroughly homogenize the sample material prior to filling the remaining sample containers. Refer to Section 5.2.2 of this procedure.
4. Follow steps 4 and 5 listed under Section 5.3 of this procedure.

## 5.7 Excavation and Sampling of Test Pits and Trenches

### 5.7.1 Applicability

This subsection presents routine test pit or trench excavation techniques and specialized techniques that are applicable under certain conditions.

During the excavation of trenches or pits at hazardous waste sites, several health and safety concerns arise which control the method of excavation. No personnel shall enter any test pit or excavation except as a last resort, and then only under direct supervision of a Competent Person (as defined in 29 CFR 1929.650 of Subpart P - Excavations). Whenever possible, all required chemical and lithological samples should be collected using the excavator bucket or other remote sampling apparatus. If entrance is still required, all test pits or excavations must be stabilized by bracing the pit sides using specifically designed wooden or steel support structures. Personnel entering the excavation may be exposed to toxic or explosive gases and oxygen-deficient environments. Any entry may constitute a Confined Space and must be done in conformance with all applicable regulations. In these cases, substantial air monitoring is required before entry, and appropriate respiratory gear and protective clothing is mandatory. There must be at least two persons present at the immediate site before entry by one of the investigators. The reader shall



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refer to OSHA regulations 29 CFR 1926, 29 CFR 1910.120, 29 CFR 1910.134, AND 29 CFR 1910.146.

Excavations are generally not practical where a depth of more than about 15 feet is desired, and they are usually limited to a few feet below the water table. In some cases, a pumping system may be required to control water levels within the pit, providing that pumped water can be adequately stored or disposed. If data on soils at depths greater than 15 feet are required, the data are usually obtained through test borings instead of test pits.

In addition, hazardous wastes may be brought to the surface by excavation equipment. This material, whether removed from the site or returned to the subsurface, must be properly handled according to any and all applicable federal, state, and local regulations.

### 5.7.2 Test Pit and Trench Excavation

These procedures describe the methods for excavating and logging test pits and trenches excavated to determine subsurface soil and rock conditions. Test pit operations shall be logged and documented as described in SOP SA-6.3.

Test pits and trenches may be excavated by hand or by power equipment to permit detailed description of the nature and contamination of the in-situ materials. The size of the excavation will depend primarily on the following:

- The purpose and extent of the exploration.
- The space required for efficient excavation.
- The chemicals of concern.
- The economics and efficiency of available equipment.

Test pits normally have a cross section that is 4 to 10 feet square; test trenches are usually 3 to 6 feet wide and may be extended for any length required to reveal conditions along a specific line. The following table, which is based on equipment efficiencies, gives a rough guide for design consideration:

Equipment	Typical Widths, in Feet
Trenching machine	2
Backhoe	2-6
Track dozer	10
Track loader	10
Excavator	10
Scraper	20

The lateral limits of excavation of trenches and the position of test pits shall be carefully marked on area base maps. If precise positioning is required to indicate the location of highly hazardous waste materials, nearby utilities, or dangerous conditions, the limits of the excavation shall be surveyed. Also, if precise determination of the depth of buried materials is needed for design or environmental assessment purposes, the elevation of the ground surface at the test pit or trench location shall also be determined by survey. If the test pit/trench will not be surveyed immediately,



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it shall be backfilled and its position identified with stakes placed in the ground at the margin of the excavation for later surveying.

The construction of test pits and trenches shall be planned and designed in advance as much as possible. However, field conditions may necessitate revisions to the initial plans. The final depth and construction method shall be determined by the field geologist. The actual layout of each test pit, temporary staging area and spoils pile will be predicated based on site conditions and wind direction at the time the test pit is made. Prior to excavation, the area can be surveyed by magnetometer or metal detector to identify the presence of underground utilities or drums.

As mentioned previously, no personnel shall enter any test pit or excavation except as a last resort, and then only under direct supervision of a Competent Person. If entrance is still required, Occupational Safety and Health Administration (OSHA) requirements must be met (e.g., walls must be braced with wooden or steel braces, ladders must be in the hole at all times, and a temporary guardrail must be placed along the surface of the hole before entry). It is emphasized that the project data needs should be structured such that required samples can be collected without requiring entrance into the excavation. For example, samples of leachate, groundwater, or sidewall soils can be taken with telescoping poles, etc.

Dewatering may be required to assure the stability of the side walls, to prevent the bottom of the pit from heaving, and to keep the excavation dry. This is an important consideration for excavations in cohesionless material below the groundwater table. Liquids removed as a result of dewatering operations must be handled as potentially contaminated materials. Procedures for the collection and disposal of such materials should be discussed in the site-specific project plans.

### **5.7.3 Sampling in Test Pits and Trenches**

#### **5.7.3.1 General**

Test pits and trenches are usually logged as they are excavated. Records of each test pit/trench will be made as described in SOP SA-6.3. These records include plan and profile sketches of the test pit/trench showing materials encountered, their depth and distribution in the pit/trench, and sample locations. These records also include safety and sample screening information.

Entry of test pits by personnel is extremely dangerous, shall be avoided unless absolutely necessary, and can occur only after all applicable Health and Safety and OSHA requirements have been met.

The final depth and type of samples obtained from each test pit will be determined at the time the test pit is excavated. Sufficient samples are usually obtained and analyzed to quantify contaminant distribution as a function of depth for each test pit. Additional samples of each waste phase and any fluids encountered in each test pit may also be collected.

In some cases, samples of soil may be extracted from the test pit for reasons other than waste sampling and chemical analysis, for instance, to obtain geotechnical information. Such information would include soil types, stratigraphy, strength, etc., and could therefore entail the collection of disturbed (grab or bulk) or relatively undisturbed (hand-carved or pushed/driven) samples, which can be tested for geotechnical properties. The purposes of such explorations are very similar to those of shallow exploratory or test borings, but often test pits offer a faster, more cost-effective method of sampling than installing borings.



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### 5.7.3.2 Sampling Equipment

The following equipment is needed for obtaining samples for chemical or geotechnical analysis from test pits and trenches:

- Backhoe or other excavating machinery.
- Shovels, picks and hand augers, stainless steel trowels.
- Sample container - bucket with locking lid for large samples; appropriate bottleware for chemical or geotechnical analysis samples.
- Polyethylene bags for enclosing sample containers; buckets.
- Remote sampler consisting of 10-foot sections of steel conduit (1-inch-diameter), hose clamps and right angle adapter for conduit (see Attachment B).

### 5.7.3.3 Sampling Methods

The methods discussed in this section refer to test pit sampling from grade level. If test pit entry is required, see Section 5.7.3.4.

- Excavate trench or pit in several depth increments. After each increment, the operator will wait while the sampler inspects the test pit from grade level to decide if conditions are appropriate for sampling. (Monitoring of volatiles by the SSO will also be used to evaluate the need for sampling.) Practical depth increments range from 2 to 4 feet.
- The backhoe operator, who will have the best view of the test pit, will immediately cease digging if:
- Any fluid phase or groundwater seepage is encountered in the test pit.
- Any drums, other potential waste containers, obstructions or utility lines are encountered.
- Distinct changes of material are encountered.

This action is necessary to permit proper sampling of the test pit and to prevent a breach of safety protocol. Depending upon the conditions encountered, it may be required to excavate more slowly and carefully with the backhoe.

For obtaining test pit samples from grade level, the following procedure shall be followed:

- Remove loose material to the greatest extent possible with backhoe.
- Secure walls of pit if necessary. (There is seldom any need to enter a pit or trench which would justify the expense of shoring the walls. All observations and samples should be taken from the ground surface.)
- Samples of the test pit material are to be obtained either directly from the backhoe bucket or from the material once it has been deposited on the ground. The sampler or Field Operations Leader directs the backhoe operator to remove material from the selected depth or location within the test pit/trench. The bucket is brought to the surface and moved away from the pit.



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The sampler and/or SSO then approaches the bucket and monitors its contents with a photoionization or flame ionization detector. The sample is collected from the center of the bucket or pile and placed in sample containers using a decontaminated stainless steel trowel or spatula.

- If a composite sample is desired, several depths or locations within the pit/trench are selected and a bucket is filled from each area. It is preferable to send individual sample bottles filled from each bucket to the laboratory for compositing under the more controlled laboratory conditions. However, if compositing in the field is required, each sample container shall be filled from materials that have been transferred into a mixing bucket and homogenized. Note that homogenization/compositing is not applicable for samples to be subjected to volatile organic analysis.
- Using the remote sampler shown in Attachment B, samples can be taken at the desired depth from the side wall or bottom of the pit. The face of the pit/trench shall first be scraped (using a long-handled shovel or hoe) to remove the smeared zone that has contacted the backhoe bucket. The sample shall then be collected directly into the sample jar, by scraping with the jar edge, eliminating the need to utilize samplers and minimizing the likelihood of cross-contamination. The sample jar is then capped, removed from the assembly, and packaged for shipment.
- Complete documentation as described in SOP SA-6.3.

#### 5.7.3.4 In-Pit Sampling

Under rare conditions, personnel may be required to enter the test pit/trench. This is necessary only when soil conditions preclude obtaining suitable samples from the backhoe bucket (e.g., excessive mixing of soils or wastes within the test pit/trench) or when samples from relatively small discrete zones within the test pit are required. This approach may also be necessary to sample any seepage occurring at discrete levels or zones in the test pit that are not accessible with remote samplers.

In general, personnel shall sample and log pits and trenches from the ground surface, except as provided for by the following criteria:

- There is no practical alternative means of obtaining such data.
- The Site Safety Officer and Competent Person determines that such action can be accomplished without breaching site safety protocol. This determination will be based on actual monitoring of the pit/trench after it is dug (including, at a minimum, measurements of volatile organics, explosive gases and available oxygen).
- A Company-designated Competent Person determines that the pit/trench is stable or is made stable (by grading the sidewalls or using shoring) prior to entrance of any personnel. OSHA requirements must be strictly observed.

If these conditions are satisfied, one person will enter the pit/trench. On potentially hazardous waste sites, this individual will be dressed in safety gear as required by the conditions in the pit, usually Level B. He/she will be affixed to a safety rope and continuously monitored while in the pit.



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A second individual will be fully dressed in protective clothing including a self-contained breathing device and on standby during all pit entry operations. The individual entering the pit will remain therein for as brief a period as practical, commensurate with performance of his/her work. After removing the smeared zone, samples shall be obtained with a decontaminated trowel or spoon. As an added precaution, it is advisable to keep the backhoe bucket in the test pit when personnel are working below grade. Such personnel can either stand in or near the bucket while performing sample operations. In the event of a cave-in they can either be lifted clear in the bucket, or at least climb up on the backhoe arm to reach safety.

#### 5.7.3.5 Geotechnical Sampling

In addition to the equipment described in Section 5.7.3.2, the following equipment is needed for geotechnical sampling:

- Soil sampling equipment, similar to that used in shallow drilled boring (i.e., open tube samplers), which can be pushed or driven into the floor of the test pit.
- Suitable driving (i.e., a sledge hammer) or pushing (i.e., the backhoe bucket) equipment which is used to advance the sampler into the soil.
- Knives, spatulas, and other suitable devices for trimming hand-carved samples.
- Suitable containers (bags, jars, tubes, boxes, etc.), labels, wax, etc. for holding and safely transporting collected soil samples.
- Geotechnical equipment (pocket penetrometer, torvane, etc.) for field testing collected soil samples for classification and strength properties.

Disturbed grab or bulk geotechnical soil samples may be collected for most soils in the same manner as comparable soil samples for chemical analysis. These collected samples may be stored in jars or plastic-lined sacks (larger samples), which will preserve their moisture content. Smaller samples of this type are usually tested for their index properties to aid in soil identification and classification, while larger bulk samples are usually required to perform compaction tests.

Relatively undisturbed samples are usually extracted in cohesive soils using open tube samplers, and such samples are then tested in a geotechnical laboratory for their strength, permeability and/or compressibility. The techniques for extracting and preserving such samples are similar to those used in performing Shelby tube sampling in borings, except that the sampler is advanced by hand or backhoe, rather than by a drill rig. Also, the sampler may be extracted from the test pit by excavation around the sampler when it is difficult to pull it out of the ground. If this excavation requires entry of the test pit, the requirements described in Section 5.7.3.4 of this procedure must be followed. The open tube sampler shall be pushed or driven vertically into the floor or steps excavated in the test pit at the desired sampling elevations. Extracting tube samples horizontally from the walls of the test pit is not appropriate, because the sample will not have the correct orientation.

A sledge hammer or the backhoe may be used to drive or push the sampler or tube into the ground. Place a piece of wood over the top of the sampler or sampling tube to prevent damage during driving/pushing of the sample. Pushing the sampler with a constant thrust is always preferable to driving it with repeated blows, thus minimizing disturbance to the sample. If the sample cannot be extracted by rotating it at least two revolutions (to shear off the sample at the bottom), hand-excavate to remove the soil from around the sides of the sampler. If hand-



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excavation requires entry of the test pit, the requirements in Section 5.7.3.4 of this procedure must be followed. Prepare, label, pack and transport the sample in the required manner, as described in SOP SA-6.3.

#### **5.7.4 Backfilling of Trenches and Test Pits**

All test pits and excavations must be either backfilled, covered, or otherwise protected at the end of each day. No excavations shall remain open during non working hours unless adequately covered or otherwise protected.

Before backfilling, the onsite crew shall photograph all significant features exposed by the test pit and trench and shall include in the photograph a scale to show dimensions. Photographs of test pits shall be marked to include site number, test pit number, depth, description of feature, and date of photograph. In addition, a geologic description of each photograph shall be entered in the site logbook. All photographs shall be indexed and maintained as part of the project file for future reference.

After inspection, backfill material shall be returned to the pit under the direction of the FOL.

If a low permeability layer is penetrated (resulting in groundwater flow from an upper contaminated flow zone into a lower uncontaminated flow zone), backfill material must represent original conditions or be impermeable. Backfill could consist of a soil-bentonite mix prepared in a proportion specified by the FOL (representing a permeability equal to or less than original conditions). Backfill can be covered by "clean" soil and graded to the original land contour. Revegetation of the disturbed area may also be required.

#### **5.8 Records**

The appropriate sample log sheet (see SOP SA-6.3; Field Documentation) must be completed by the site geologist/sampler. All soil sampling locations must be documented by tying in the location of two or more nearby permanent landmarks (building, telephone pole, fence, etc.) and shall be noted the appropriate sample log sheet, site map, or field notebook. Surveying may also be necessary, depending on the project requirements.

Test pit logs (see SOP SA-6.3; Field Documentation) shall contain a sketch of pit conditions. In addition, at least one photograph with a scale for comparison shall be taken of each pit. Included in the photograph shall be a card showing the test pit number. Boreholes, test pits and trenches shall be logged by the field geologist in accordance with SOP GH-1.5.

Other data to be recorded in the field logbook include the following:

- Name and location of job.
- Date of boring and excavation.
- Approximate surface elevation.
- Total depth of boring and excavation.
- Dimensions of pit.
- Method of sample acquisition.
- Type and size of samples.
- Soil and rock descriptions.
- Photographs.
- Groundwater levels.



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- Organic gas or methane levels.
- Other pertinent information, such as waste material encountered.

## 6.0 REFERENCES

American Society for Testing and Materials, 1987. ASTM Standards D1587-83 and D1586-84. ASTM Annual Book of Standards. ASTM. Philadelphia, Pennsylvania. Volume 4.08.

NUS Corporation, 1986. Hazardous Material Handling Training Manual.

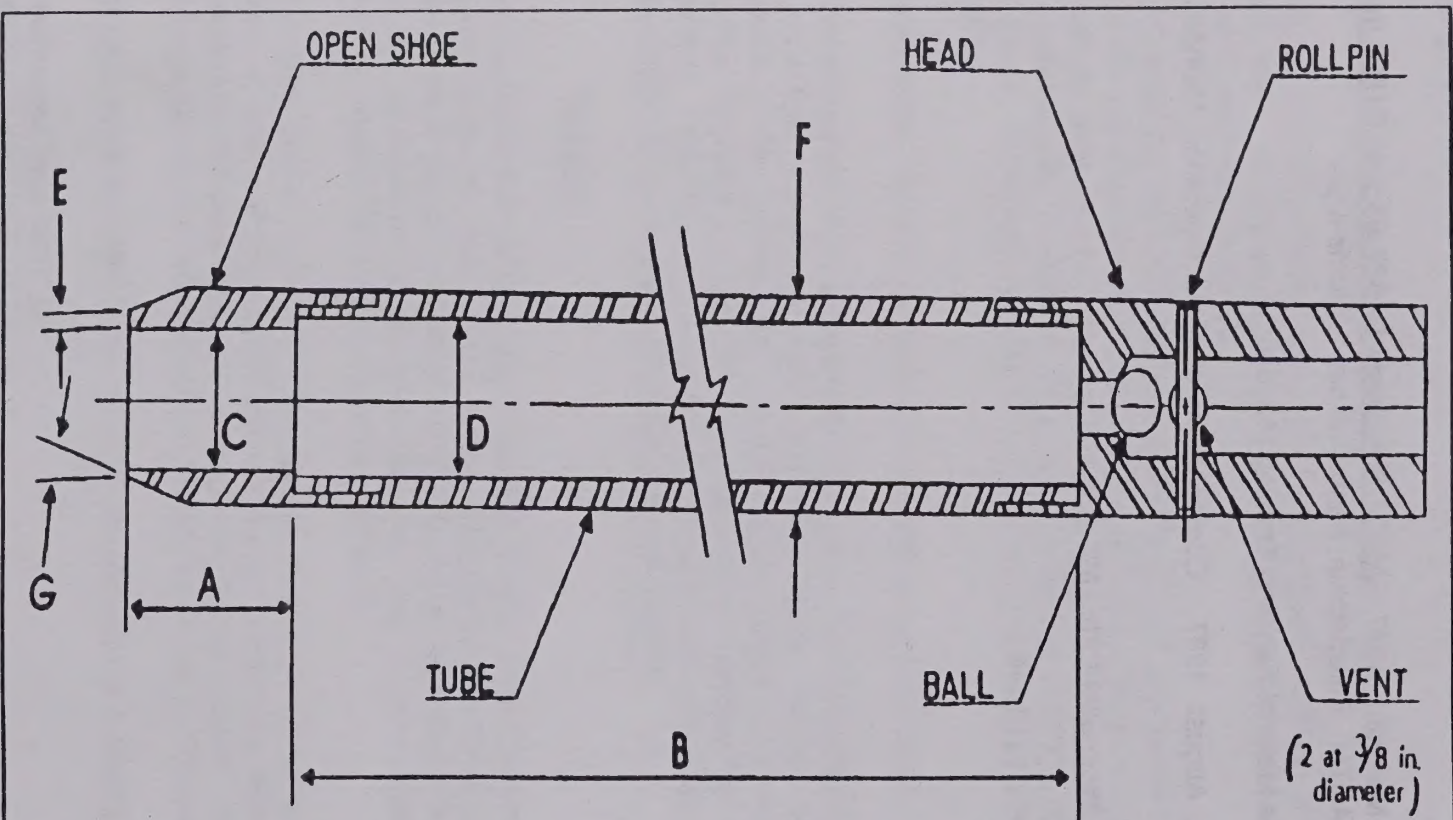
NUS Corporation and CH2M Hill, August, 1987. Compendium of Field Operation Methods. Prepared for the U.S. EPA.

OSHA, Excavation, Trenching and Shoring 29 CFR 1926.650-653.

OSHA, Confined Space Entry 29 CFR 1910.146.



ATTACHMENT A  
SPLIT-SPOON SAMPLER



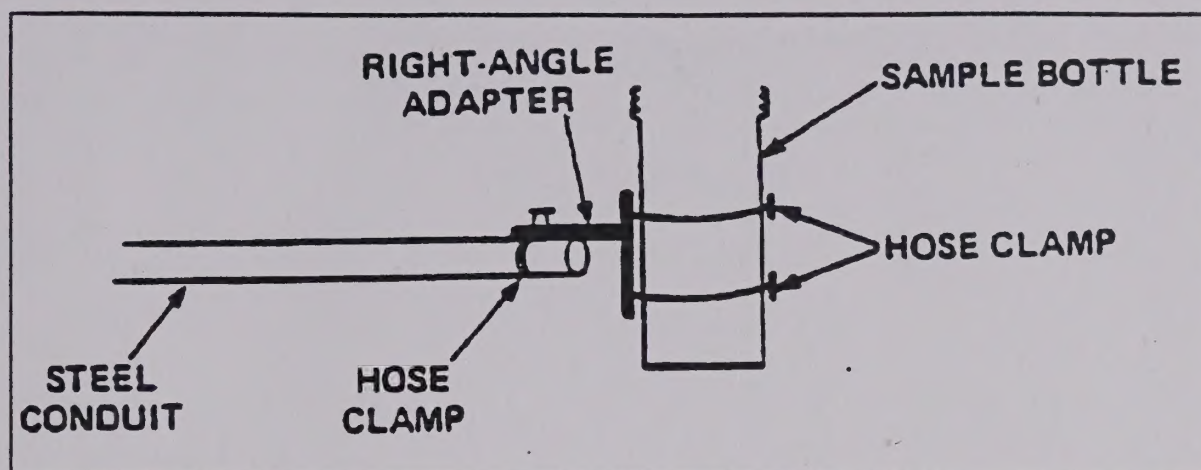
- A = 1.0 to 2.0 in. (25 to 50 mm)
- B = 18.0 to 30.0 in. (0.457 to 0.762 m)
- C =  $1.375 \pm 0.005$  in. ( $34.93 \pm 0.13$  mm)
- D =  $1.50 \pm 0.05 - 0.00$  in. ( $38.1 \pm 1.3 - 0.0$  mm)
- E =  $0.10 \pm 0.02$  in. ( $2.54 \pm 0.25$  mm)
- F =  $2.00 \pm 0.05 - 0.00$  in. ( $50.8 \pm 1.3 - 0.0$  mm)
- G =  $16.0^\circ$  to  $23.0^\circ$

The  $1\frac{1}{2}$  in. (38 mm) inside diameter split barrel may be used with a 16-gage wall thickness split liner. The penetrating end of the drive shoe may be slightly rounded. Metal or plastic retainers may be used to retain soil samples.

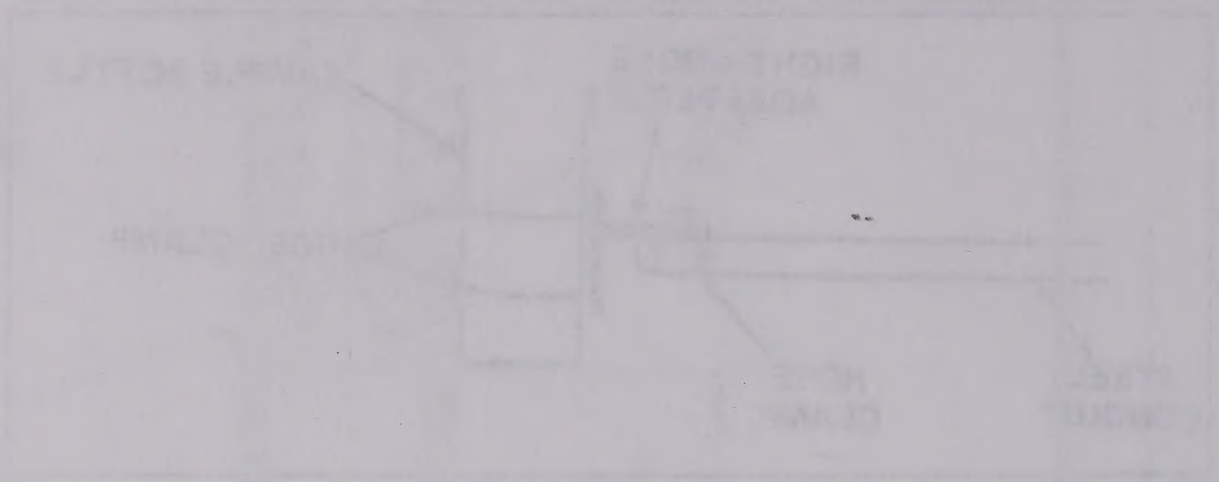


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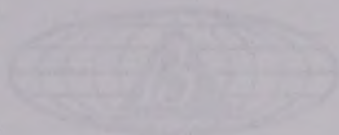
**ATTACHMENT B  
REMOTE SAMPLE HOLDER FOR TEST PIT/TRENCH SAMPLING**











BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

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Approved	
BAR Environmental Inc.	
Prepared	
Earth Sciences Department	
Approved	
D. Smith	

1.00 WATER SAMPLING SYSTEMS AND GEOHYDROLOGY IN  
THE UNSATURATED ZONE

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BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

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Subject WATER SAMPLING SYSTEMS AND GEOHYDROLOGY IN  
THE UNSATURATED (VADOSE) ZONE

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## 1.0 PURPOSE

This procedure describes the general concepts of vadose (unsaturated) zone monitoring and sampling at hazardous waste sites. Several specific methods of monitoring and sampling are also described.

## 2.0 SCOPE

This procedure applies to any hazardous waste sites which require vadose zone monitoring and/or sampling.

## 3.0 GLOSSARY

Bulk Density - The density of a soil or rock, including solids plus voids, after oven-drying at 105 degrees Centigrade to constant weight. Also called dry density.

Capillary Zone (Capillary Fringe) - The transition between the vadose zone and the saturated zone. The soil-water pressure is less than atmospheric, but some or all of the soil interstices (pores) are filled with water that is continuous with the water in the zone of saturation. This water is held above the water table by capillarity (the attractive force between two unlike molecules, which causes water to rise in capillary tubes) acting against gravity.

Fillable Porosity - The volume of water that an unconfined aquifer stores during a unit rise of the water table. Usually less than the specific yield because of the entrapment of air during the rise of the water table (see Section 5.2.4).

Hydraulic Conductivity (K) - A quantitative measure of the ability of porous material to transmit water. The volume of water that will flow through a unit cross-sectional area of porous material per unit time under a head gradient. Hydraulic conductivity is dependent upon properties of the medium and fluid. Also referred to as "permeability."

Infiltration - The vertical flow or movement of water through the soil surface into the ground under the influence of gravity. The maximum rate at which water enters a soil is the infiltration capacity.

Infiltrometer - A device for measuring infiltration rates. Sprinkler infiltrometers and cylinder infiltrometers are most commonly used.

Lysimeter - A device for obtaining water samples from unsaturated soils, consisting essentially of a porous ceramic cup bonded to an airtight tube through which access tubes for vacuum application and fluid sampling pass. When a vacuum is applied to the in-place lysimeter, soil pore water flows into the cup. The water is recovered by pressurizing the lysimeter, forcing water up the sampling tube.

Perched Groundwater - Groundwater separated from the water table by an impermeable bed of soil or rock, which is underlain by unsaturated materials. Perched groundwater forms a perched water table.

Porosity - Percentage of the total volume of a soil or rock occupied by pores or other openings. Effective porosity is that volume of connected pore space which is available for fluid transmission.

Psychrometer - A device for measuring soil-water pressure under very dry conditions.

Saturated - Rock or soil is saturated with respect to water if all of its fillable interstices (pores) are filled with water.



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Specific Retention (Field Capacity) - The amount of water held in a soil by capillary action after gravitational water has percolated downward and drained away; expressed as a ratio (percentage) of the volume of water retained per unit volume of soil. Field capacity is a similar measure, but it is expressed as a ratio of the weight of water retained per unit weight of soil.

Specific Yield - The amount of water that a saturated soil will yield by gravitational drainage; expressed as a ratio (percentage) of the volume of water drained per unit volume of soil. In a saturated soil, the sum of specific yield plus specific retention equals the effective porosity.

Tensiometer - A device for measuring negative soil-water (i.e., less than atmospheric) pressure. It consists basically of a porous ceramic cup bonded to an airtight, water-filled tube from which a small diameter tube leads to a mercury manometer or pressure gauge.

Vadose Zone - Soil zone above the zone of saturation, i.e., the zone of aeration. The vadose zone may contain some saturated areas (i.e., perched water).

Water Table - A surface in an aquifer where groundwater pressure is equal to atmospheric pressure (i.e., the pressure head is zero) and below which all strata are saturated with water.

#### 4.0 RESPONSIBILITIES

Project Manager with input from the project geohydrologist and geochemist is responsible for determining that vadose zone monitoring or sampling is necessary, and for developing an adequate program (as part of the Work Plan and/or Sampling and Analysis Plan) to accomplish this.

Geohydrologist and Geochemist is responsible for alerting the Project Manager that vadose zone sampling may be required, since this solid zone is often overlooked as a migration pathway or reservoir for contaminants. Also responsible for determining which properties of the vadose zone need to be determined, and the proper methods for acquiring that information.

#### 5.0 PROCEDURES

##### 5.1 General

Although soil sampling is usually undertaken in the vadose zone, sampling of vadose zone water and soil gas is often overlooked. Of course, the need for vadose zone sampling depends on conditions of the site and contaminants present. If the water table is relatively shallow (less than 10-15 feet below the surface) and vadose zone materials consist of coarse sands and gravels or fractured rock, the vadose zone will probably minimally affect contaminant migration and retention.

If, however, the vadose zone is thick (it may be hundreds of feet thick in arid areas), its properties will be important in the migration of fluids from the ground surface to the water table, and some (or all) of the contamination may be retained in the vadose zone, either adsorbed to soil, in soil water or perched groundwater, or in soil gas.

##### 5.1.1 Geohydrologic Framework of the Vadose Zone

The geological profile extending from the ground surface to the upper surface of the principal water-bearing formation is called the vadose zone. The term "vadose zone" is preferable to the often-used term "unsaturated zone," because saturated regions are frequently present in some vadose zones. The vadose



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zones can be subdivided into three regions designated as: the surface soil zone, the intermediate vadose zone, and the capillary fringe.

The surface soil zone is generally recognized as that region that manifests the effects of weathering of native geological material. The movement of water in the surface soil zone occurs mainly as unsaturated flow caused by infiltration, percolation, redistribution, and evaporation. In some soils, primarily those containing horizons of low permeability, saturated regions may develop during surface flooding, creating shallow perched water tables.

Weathered materials of the soil zone may gradually merge with underlying deposits, which are generally unweathered, comprising the intermediate vadose zone. This zone may range in thickness from being practically non-existent to several hundred feet (e.g., in arid western alluvial basins). Water in the intermediate vadose zone may exist primarily in the unsaturated state, and in regions receiving little inflow from above, flow velocities may be negligible. Perched groundwater, however, may develop above low permeability layers or lenses. Such perched layers may be hydraulically connected to ephemeral or perennial stream channels so that, respectively, temporary or permanent perched water tables may develop. These layers can serve as underground spreading regions, transmitting water and contaminants laterally away from the overlying source area. Eventually, water either leaks downward from these layers to the water table, discharges laterally, or it evaporates. Any of these conditions can lead to the presence of contamination at unexpected locations.

Alternatively, saturated conditions may develop in the intermediate vadose zone as a result of deep percolation of water from the soil zone during prolonged surface application (e.g., infiltration of leachate from a lagoon), leading to the development of a groundwater mound.

The base of the vadose zone (the capillary fringe) merges with underlying saturated deposits of the principal water-bearing formation. This zone is not characterized as much by the nature of geological materials, as it is by the presence of water under conditions of saturation or near saturation. Both the hydraulic conductivity and flux of fluid may remain high for some vertical distance in the capillary fringe, depending on the nature of the materials. In general, the thickness of the capillary fringe is greater in fine materials than in coarse deposits. It has been reported that oil percolating downward through the vadose zone may flow in a lateral direction within the capillary fringe (along the top of the water table) because of its immiscibility with water (Freeze and Cherry, 1979).

#### **5.1.2 Vadose Zone Properties Which Affect Contaminant Movement**

The three types of vadose zone properties which may require investigation are:

- Fluid storage properties
- Fluid transmission properties
- Chemistry of groundwater, soil, and soil gas

Storage properties are important in that pollutants are placed in temporary storage within the void space of the vadose zone before movement in groundwater. In some cases, such as in western alluvial basins, the storage space may be sufficient to preclude movement into underlying aquifers. The storage properties of interest are:

- Total thickness of the vadose zone
- Porosity and bulk density
- Moisture content



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- Soil-moisture potential
- Specific retention, specific yield, and fillable porosity

Information on the fluid transmission properties can indicate the velocity (or travel time) of water through the vadose zone. Contaminants may not necessarily travel at the same rate as water because of attenuation or biodegradation in the vadose zone. Consequently, the travel time of water represents an upper limit on the mobility of most pollutants. Some pollutants, however, may move at a higher rate than water because of physical and chemical properties. For example, based on differences in viscosity, the velocity of gasoline should be about 1.5 times that of water. The fluid transmission properties of interest include:

- Infiltration rate
- Porosity
- Percolation rate (unsaturated hydraulic conductivity) as a function of soil-moisture potential
- Hydraulic gradient and direction of fluid flow

Soil and groundwater chemistry can affect the movement of contaminants through the vadose zone. Soil properties which affect contaminant movement through attenuation/adsorption include:

- Mineral composition and percent organic matter
- Presence of iron/manganese oxide or organic coatings on soil particles
- Specific surface area
- Ion-exchange capacity (affects attenuation of trace metals)

Groundwater parameters which may affect contaminant movement include:

- pH
- Redox potential (pE or Eh)
- Salinity/major ion composition

In addition, bacteria in the groundwater or attached to soil particles may biodegrade contaminants in the vadose zone.

### 5.1.3 Preparation for Vadose Zone Sampling

Before initiating a vadose zone sampling program, background information should be obtained on the following items: (1) nature of pollutants, (2) pollutant source loading, (3) existing groundwater usage and quality, and (4) a description of the geohydrologic framework, including infiltration potential and hydraulic/geochemical properties of the vadose and groundwater zones. Specific, detailed soil survey data may be available through State agricultural experiment stations, the Soil Conservation Service, or other agencies. Such surveys generally include information on depths of soil horizons, presence of hardpan, clay pan, color, porosity, structure, texture, organic matter content, soil pH, and infiltration rates. Water Supply Papers of the U.S. Geological Survey (USGS) are also a good source of information.

## 5.2 Determination of Fluid Storage Properties

### 5.2.1 Vadose Zone Thickness

The storage capacity of the vadose zone is related to its overall thickness, which may fluctuate both temporally (due to seasonal or artificial recharge/discharge variation) and geographically (due to variable stratigraphy, structure and geohydrology). The simplest way to determine vadose zone thickness is to



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construct an isopleth map of the difference between ground surface elevation and the static water levels in wells (note that cascading water in wells may indicate a perched water table). Thermal infrared imagery provides an indirect method to determine the presence of perched groundwater or a shallow water table, because the heat flux through soils underlain by shallow water tables differs from that through dry soils (Everett, et al., 1983). In addition, geophysical methods (resistivity or conductivity surveys) can give an indication of the depth to the water table.

### 5.2.2 Porosity and Bulk Density

Bulk density and porosity are best measured on undisturbed core samples in a geotechnical laboratory. Bulk densities generally range from 1.3 gm/cm (80 lb/cubic ft.) for clay soils, to 2.1 gm/cm (130 lb/cubic ft.) for sandy soils. The pore size distribution and degree of interconnection can also affect specific retention of water. Sandy soils have large, uniform-sized pores allowing easy drainage; loamy soils (containing a mixture of clay, silt and sand) may be more porous than sands, but have a wider pore size distribution and poorer interconnection, leading to slower drainage and greater water retention.

### 5.2.3 Moisture Content

The volumetric moisture content ( $\Theta$ ) is defined as:

$$\Theta = V_w/V_t$$

where  $V_w$  = volume of soil moisture and  
 $V_t$  = volume of total sample.

The soil moisture content can be determined on carefully preserved samples (to avoid loss of moisture), or in the field using the following techniques:

- Neutron moisture logging uses a geophysical logging device lowered down a borehole, or a neutron probe emplaced in the soil.
- Gamma-gamma logging uses a geophysical logging device lowered down a borehole.
- Resistivity or conductivity surveys conducted along the ground surface.
- Electrical resistance blocks, consisting of two electrodes embedded in a porous matrix, emplaced in the soil.
- Heat dissipation sensors, consisting of a diode with a heating circuit embedded in a porous matrix, emplaced in the soil.
- Capacitance sensors, consisting of a pair of electrodes emplaced in the soil.
- Tensiometers emplaced in the soil.

The relative advantages and disadvantages of these methods are presented in Attachment A.

### 5.2.4 Soil Moisture Potential

The theoretical maximum saturation value of soil is the effective porosity. As soil drains, a range of soil-water content values is possible, depending on various forces acting on the solids-water system. The



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soil-moisture potential (soil-water pressure) is a measure of these forces, which include gravitational, osmotic and matrix forces. Matrix forces include forces related to the surface tension of water, the cohesion of water molecules, the adhesion of water molecules to the surface of soil particles, and electrical forces at the molecular level. The soil moisture potential is usually expressed in terms of pressure (energy per unit volume) or an equivalent head of water which is energy per unit weight. When the soil water exists below atmospheric pressure, the pressure potential is considered negative. The negative pressure potential, or matrix potential, is often called the soil suction.

Soil-moisture potential is important because liquids in the vadose zone migrate in response to gradients in soil moisture potential, just as groundwater always flows down the hydraulic soil moisture potential, one can determine the direction of liquid movement and one may even be able to estimate the velocity of flow.

The relationship between soil-moisture potential and water content is termed the soil-moisture characteristic. The moisture content for a given soil at a particular soil-moisture potential (suction) will vary depending on whether the soil is in a wetting or drying cycle. The moisture content at a given suction is greater during a drying cycle than during a wetting cycle, because of the entrapment of air in pore spaces during wetting. This behavior is termed hysteresis, and is illustrated by the wetting and drying soil-water characteristic curves in Attachment B. When a partially drained soil is wetted, or a partially wetted soil drained, the suction-moisture content relation follows an intermediate path, or scanning curve, between the main branches.

The soil suction can be measured in the laboratory on undisturbed soil cores, or in-situ using a tensiometer or thermocouple psychrometer. Either device can be installed in clusters (at varying depths) to characterize the direction of unsaturated water movement in the vadose zone. The advantages and limitations of tensiometers are briefly described in Attachment A. The installation and use of tensiometers is similar to lysimeters and is fully described in Everett, et al. (1983). Tensiometers are relatively simple devices, and if properly installed in the soil and deaerated, they are dependable and require little servicing. If filled with ethylene glycol rather than water, they can be left in the ground during freezing conditions.

Thermocouple psychrometers measure the relative humidity of the soil pore air, which is related to the soil-moisture potential by a simple equation (Griswold and Daniel, 1984). These devices are more fragile than tensiometers and subject to corrosion, but they are not limited by freezing weather.

#### **5.2.5 Specific Retention, Specific Yield and Fillable Porosity**

Specific retention, specific yield and fillable porosity can be obtained using neutron moisture logs obtained in vadose zone sediments near the water table as the water table fluctuates (Everett, et al., 1983). Alternately, if the soil in the vadose and saturated zones are similar, the specific yield of the underlying saturated sediments can be obtained during pumping tests and it can be assumed that this represents the specific yield of the vadose zone.

### **5.3 Determination of Fluid Transmission Properties**

#### **5.3.1 Infiltration Rate**

Methods for field measurement of the soil infiltration rate are described in detail in U.S. EPA (1977) and Everett, et al. (1983). These methods consist essentially of a means of applying water (or other infiltrating liquid) at a known rate to a known surface area of soil using infiltrometers or test basins. The initial infiltration rate of a dry soil is high, but this rate decreases toward an asymptotic value (the saturated



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hydraulic conductivity) as the soil is saturated (i.e., as the soil suction potential approaches zero). Thus, the infiltration rate should be recorded as a function of time, to obtain both initial infiltration rates and saturated hydraulic conductivity (which can be used to estimate the unsaturated hydraulic conductivity).

Factors affecting the infiltration capacity of a soil include soil texture, soil structure, head of water above soil, initial and confined air, biological activity, entrained sediment, and salinity of applied water. Soil structure has a strong effect on infiltration rate, particularly at the beginning of infiltration. Water moves preferentially very rapidly through the larger cracks in the soil at the beginning of infiltration. Later, as the soil swells and closes the cracks, water movement occurs more slowly through the soil pores. Shallow impeding layers, entrapped or confined air, microbial metabolic byproducts, and entrained fine sediment all serve to reduce the infiltration rate. In clayey soils, water with a high sodium content may cause the clays to swell, also reducing the infiltration rate. Thus, infiltration tests should be conducted with the above-mentioned parameters duplicating those in existence at the time for which the infiltration rate values are needed (e.g., to estimate past infiltration from an emptied lagoon, the head of water in the full lagoon, and lagoon salinity and soil-moisture profile should be simulated).

### 5.3.2 Unsaturated Hydraulic Conductivity

The rate of water movement through the vadose zone is a function of the unsaturated hydraulic conductivity, which varies tremendously with the soil moisture content (see Attachment C) and is probably the most difficult vadose zone parameter to determine. There are several different approaches for obtaining the rate of water flow through the vadose zone, including:

- Methods based on Darcy's equation and the equation of continuity
- Water budgeting
- Direct measurement
- Tracer techniques

These methods are described briefly below, and reviewed in detail in U.S. EPA (1977), Everett, et al. (1983), and Griswold and Daniel (1984).

Darcy's equation for unsaturated flow is:

$$J = Q/A = K(\theta)$$

where

J	=	unit flux (quantity of fluid crossing a unit area per unit time)
Q	=	flow volume through an area A
K(θ)	=	unsaturated hydraulic conductivity as a function of moisture content (θ) (see Attachment C)

The average linear velocity of flow through the unsaturated zone ( $\bar{V}$ ) is expressed as:

$$\bar{V} = J/n_e$$

Where  $n_e$  is the effective porosity and is thought to be equal to the volumetric moisture content,  $\theta$  (Everett, et al., 1983, and Griswold and Daniel, 1984).



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The equation of continuity states that the change in moisture content with time through a soil profile (i.e., during drainage) is equal to the net flux of water from that profile.

However, since  $\Theta$  varies continuously with depth in unsaturated soils,  $K(\Theta)$  also varies continuously (i.e., there is a large uncertainty in the in-situ unsaturated hydraulic conductivity). In practice, the saturated hydraulic conductivity, measured, for example, by cylinder infiltrometers, is often used to determine a maximum flux or velocity since saturated  $K$  is greater than unsaturated  $K$ .

The water budget method estimates the flux at a particular point in the soil profile as the difference between total inflow (rainfall, irrigation, infiltration from ponds) plus change in storage (i.e., change in moisture content) minus other outflow parameters (runoff, evapotranspiration, drainage). This method requires accurate determination of water balance parameters and is difficult to apply in heterogeneous or highly stratified soils. Two direct measurement methods are measurement of flow through a porous tube containing a sensitive flow transducer emplaced in the soil, or measurement of the transfer of a heat pulse by soil water moving through a porous cup. The latter method requires laboratory calibration and its accuracy is questionable.

Using tracers is probably the simplest and most accurate method for measuring the flux (percolation) rate of soil water. Potential tracers include chemical tracers such as chloride ion, fluorescent dyes or fluorocarbons, and radioactive tracers such as tritium (H-3) or C1-36. Other radiotracers such as Co-60, Sr-90 or Cs-137 are not reliable due to attenuation (adsorption) by soils. With any conservative (non-attenuated) tracer, flux is measured by modeling a known input function (point or continuous) against a measured vertical tracer profile in the soil.

## 5.4 Vadose Zone Water Sampling Systems

### 5.4.1 Sampling From Unsaturated Soils

Methods to sample water from saturated soils (e.g., wells, open pits) cannot be used in unsaturated soils where negative (subatmospheric) pressures exist so that water will not drain into open cavities. Various devices to extract pore water from the vadose zone include lysimeters, filter candles, fiber samples and membrane filter samples. One of the more significant problems with all of these methods is that the use of a vacuum affects the concentration of any volatile contaminants in the soil water being sampled. An alternate method is to extract and tightly package an undisturbed soil sample from the vadose zone (via drilling methods), and to extract the soil moisture from the sample in the analytical laboratory under controlled conditions which collect and measure contaminant volatiles released during the extraction procedure.

Lysimeters - Lysimeters consist of a porous ceramic cup bonded to a PVC tube and sealed at one end. Access tubes pass through the seal for vacuum application and fluid extraction. The porous ceramic cup becomes an extension of the surrounding soil, and as a vacuum is applied to the interior of the device, pore water flows into the cup and PVC tube. Although lysimeters have limitations, they appear to be the best method available for sampling water from unsaturated soils (Everett, et al., 1983).

The three common types of lysimeters are vacuum lysimeters, pressure-vacuum lysimeters, and high pressure-vacuum lysimeters. The vacuum lysimeter is designed for sampling from shallow depths of six feet or less. A vacuum is applied using a hand vacuum-pressure pump and the sample is sucked into a collection flask. To extract samples from greater depths, a vacuum-pressure lysimeter (see Attachment D) is used. With these devices, a vacuum is applied to the system to allow the lysimeter to fill with pore water, and the system is then pressurized (with an inert gas such as nitrogen) to force the sample to the surface. Some of the water is also forced back through the cup into the surrounding soil.



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Consequently, it is not recommended that these devices be used at depths greater than 50 feet (to limit the pressure applied). To prevent the sample from being forced back through the porous cup upon application of pressure, high pressure-vacuum lysimeters were developed. This device consists of two chambers separated by a check valve (see Attachment D). After the sample is drawn through the porous cup and lower chamber and into the upper chamber (about 1 liter volume) by the vacuum, the pressure which is applied to extract the sample closes the check valve, isolating the upper chamber from the porous cup. High pressures can then be used to collect the sample without forcing it back through the porous cup into the soil. Depths greater than 100 feet can be sampled with this device.

Installation of the shallow vacuum-type samplers is similar to the installation of tensiometers. A cavity is first augered to the desired depth. Soil from the base of the hole is wetted to form a slurry (Soil Moisture Equipment Corporation, 1978). The sampler is placed in the hole, forcing the cup into the slurry. The entire cup should be covered by the slurry. The hole is then backfilled with soil, tamping to prevent side leakage.

The pressure-vacuum type lysimeters, either with or without the check valves, can be installed singly in a cavity or clustered with two or more units in a cavity. The base of the borehole should be sealed with bentonite. A layer of silica sand is then placed on top of the bentonite plug. The lowermost cup is placed on the silica sand and subsequently surrounded by more sand. Native soil is backfilled in the cavity to an elevation near that of the next sampler. Bentonite is added as a plug. Silica sand is then added, the second unit is installed, and backfilling proceeds as above. A layer of bentonite should be added above the shallowest lysimeter to prevent leakage from the surface through the relatively permeable backfill.

The aboveground assembly comprises a pressure-vacuum system and collection bottles. For a system with several samplers, a pressure-vacuum manifold assembly is advantageous. Generally, pressure should be added with an inert gas such as nitrogen to preclude oxidation of chemical constituents.

Filter Candles - The filter candle pore water sampling system consists of a porous ceramic rod ("candle") about 12 inches long and 1-1/4 inches in diameter, placed within a galvanized sheet metal trough. A plastic pipe connects the rod to a sampling bottle in a nearby manhole or trench. The sheet metal trough is filled with soil, placed in a rectangular horizontal cavity (formed by first augering a horizontal hole at the desired depth, then forcing a rectangular shaper into the hole) and pressed against the in-situ soil above the trough with a rubber air pillow or mechanical jack (see Attachment E). The vacuum which is applied to the system is determined from adjacent tensiometers so that groundwater flows into the candles at the same rate as the surrounding soil (Everett, et al., 1983, and Griswold and Daniel, 1984). The drawback of this system is that it requires construction of a trench or manhole and excavation of the horizontal cavity in which the filter candle is placed. Filter candles are therefore more appropriate to emplace during construction (e.g., of a landfill) rather than during a remedial investigation.

Hollow Fiber Samples - These samples consist of bundles of semi-permeable cellulose acetate hollow fibers, which are installed and function in a manner similar to filter candles. These devices permit rapid collection of samples without significantly affecting natural flow conditions (Everett, et al., 1983, and Griswold and Daniel, 1984). However, the cellulose acetate material may be subject to biodegradation.

Membrane Filter Samplers - Membrane filter samplers consist of a "Swinnex"-type filter holder (syringe filter) containing a polycarbonate or cellulose acetate filter and a glass fiber pre-filter. The sampler is placed in a hole containing several sheets of glass fiber "collectors" and smaller glass fiber "wick" disks that are in contact with the pre-filter (see Attachment E). Soil water enters the "collectors" by capillarity. When a vacuum is applied to the filtering system, the water flows up the "wick" disks and into the filter holder. Using the "wick" disks and pre-filter, clogging of the membrane filter by fine material is



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minimized. These samplers are inexpensive to construct and install, and allow contact with a large soil area, but can operate only over a limited range of soil moisture (flow cannot be generated under low moisture conditions).

The range of applications and limitations of the various types of suction samplers are similar and may be grouped as follows: soil physical properties; soil moisture limitations; sampler-wastewater interactions; and climatic factors. With regard to soil physical properties, contact between the cup (or filter) is difficult to maintain in very coarse textures soils (sands and gravels). Furthermore, in highly structured soils and fractured material, the composition of fluid in cracks may differ from that in pores. Cups and filters sample only from small pores. Consequently, samples may not be representative of "average" fluid.

Low soil moisture prevents samples from being obtained (when soils dry to the point that air enters the cups when applying a vacuum). Sampler-wastewater interactions include plugging of cups or filters by soil fines, bacteria or chemical precipitates, and potential adsorption of heavy metals or organics on the cup or filter. Various experiments (described in Morrison, 1983) have shown that lysimeter cups can:

- "Filter" fecal coliforms, reducing the counts in recovered water by two to four orders-of-magnitude.
- Reduce concentrations of Ni, Cu, Pb, Zn, Fe, and Mn by 5 to 10 percent.
- Adsorb phosphorus and ammonia.
- Reduce concentrations of chlorinated hydrocarbons (DDT, DDE, DDD) by 70 to 94 percent.

Climatic limitations refer to freezing, which may rupture the samplers if they contain water, or shift them during freeze-thaw cycles so that they lose contact with the soil.

#### 5.4.2 Sampling Perched Groundwater

Shallow perched groundwater can be sampled using the following methods:

- Tile drains
- Collection pans and manifolds
- Wells
- Piezometers
- Multilevel samples (e.g., Barcad samplers)

The latter three methods are common techniques in groundwater sampling.

If a tile drainage system has been installed to control the elevation of a perched groundwater table, samples can be collected from the tile outfall. Collection pans and manifolds can also be installed in areas where temporary saturation lenses develop during the percolation of water from overlying surface sources. In construction, pan collectors are similar to the filter candle troughs, except that a ceramic filter candle is not included. Thus, the media in the trough (usually gravel, to prevent clogging) must be saturated. Commonly, the collector pans are connected to a central chamber or trench containing sample bottles and accessories. Both tile drains and collection pans are more commonly constructed as part of the monitoring system at a new site (i.e., a landfill) or during remedial construction, and are not frequently used for remedial investigation (RI) purposes. A perched water sampling system can also be constructed using geosynthetics (layers of impermeable geomembrane, geonet, and geotextile) as is used for leachate collection and monitoring at new landfills.



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#### 5.4.3 Sample Handling and Management

The guidance provided in the following procedures should be followed with regard to sample containers, preservation, shipment and documentation.

- Non-Radiological Sample Handling (Procedure SA-6.1)
- Field Documentation (Procedure SA-6.3)

#### 6.0 REFERENCES

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U.S. EPA, 1977. Process Design Manual for Land Treatment of Municipal Wastewater. EPA-625/1-77-008, U.S. Environmental Protection Agency Center for Environmental Research Information, Cincinnati, Ohio.

#### 7.0 ATTACHMENTS

- Attachment A - Advantages and Limitations of Soil Moisture Content Measuring Devices
- Attachment B - Soil-water Characteristic Curves for Wetting and Drying, Illustrating Hysteresis
- Attachment C - Typical Unsaturated Hydraulic Conductivity versus Soil Moisture Curve
- Attachment D - Vacuum-pressure and High-pressure Vacuum Lysimeters
- Attachment E - Filter Candle and Membrane Filter Samplers



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## ATTACHMENT A

### ADVANTAGES AND LIMITATIONS OF SOIL MOISTURE CONTENT MEASURING DEVICES

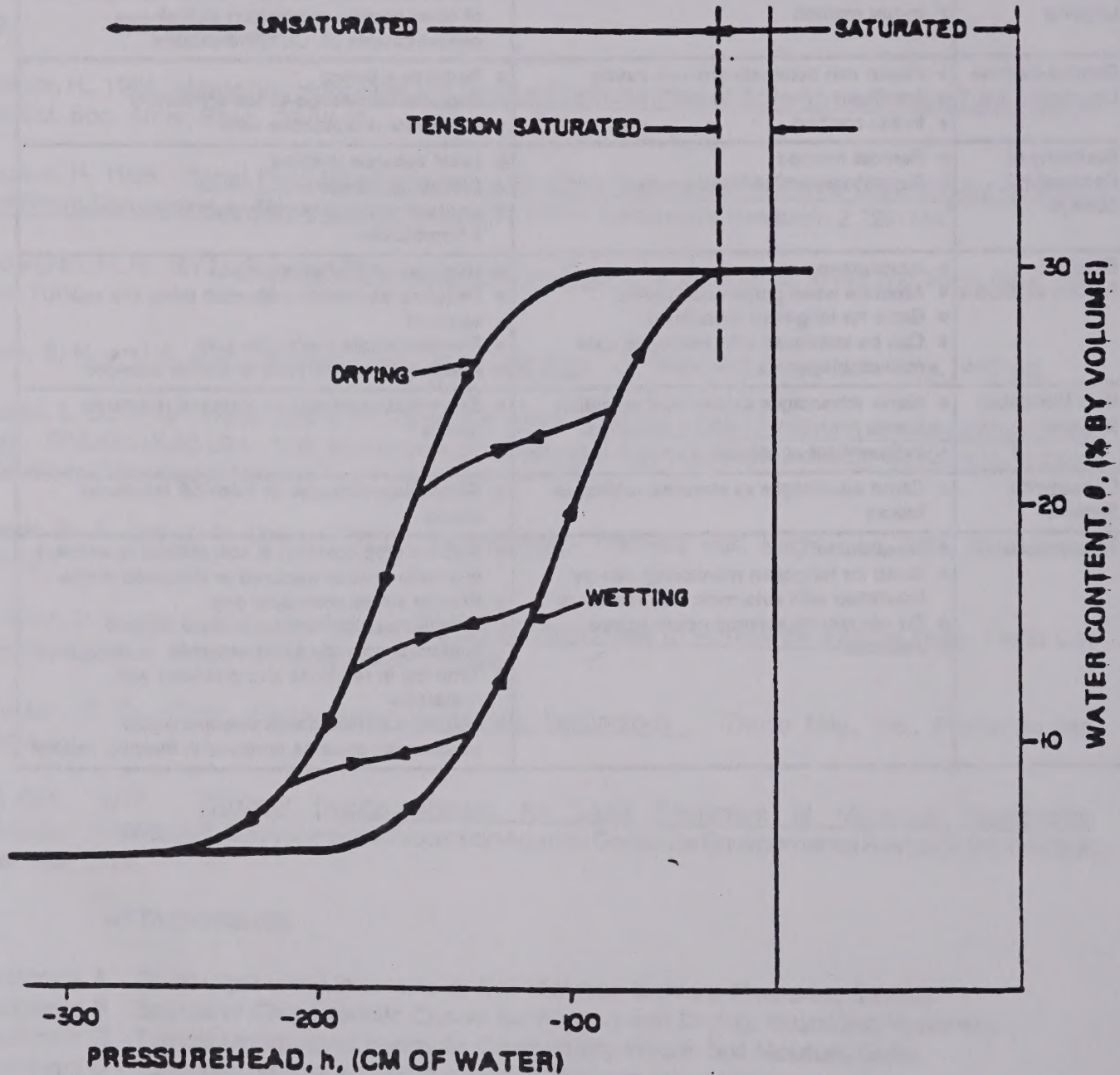
Method	Advantages	Disadvantages/Limitations
Neutron Moisture Logging	<ul style="list-style-type: none"> <li>● Rapid and accurate in uncased or steel-cased wells</li> <li>● In-situ method</li> </ul>	<ul style="list-style-type: none"> <li>● Requires a boring or emplacement in soil</li> <li>● Not accurate in plastic-cased wells or in presence of other neutron-moderators at high concentrations (B, Cl, hydrocarbons)</li> </ul>
Gamma-Gamma Logging	<ul style="list-style-type: none"> <li>● Rapid; can penetrate any well casing</li> <li>● Accurate</li> <li>● In-situ method</li> </ul>	<ul style="list-style-type: none"> <li>● Requires a boring</li> <li>● Requires knowledge of soil dry density</li> <li>● Inaccurate in expansive soils</li> </ul>
Resistivity or Conductivity Surveys	<ul style="list-style-type: none"> <li>● Remote method</li> <li>● Rapid/Inexpensive for large areas</li> </ul>	<ul style="list-style-type: none"> <li>● Least accurate method</li> <li>● Difficult to interpret</li> <li>● Contaminant plumes may lead to erroneous interpretation</li> </ul>
Electrical Resistance Blocks	<ul style="list-style-type: none"> <li>● Inexpensive</li> <li>● Accurate when properly calibrated</li> <li>● Good for long-term monitoring</li> <li>● Can be interfaced with automatic data recording systems</li> </ul>	<ul style="list-style-type: none"> <li>● Requires emplacement in soil</li> <li>● Requires laboratory calibration using site soil samples</li> <li>● Provides single point data only</li> <li>● Affected by temperature or salinity changes</li> </ul>
Heat Dissipation Sensors	<ul style="list-style-type: none"> <li>● Same advantages as electrical resistance blocks</li> <li>● Independent of soil salinity</li> </ul>	<ul style="list-style-type: none"> <li>● Same disadvantages as electrical resistance blocks</li> </ul>
Capacitance Sensors	<ul style="list-style-type: none"> <li>● Same advantages as electrical resistance blocks</li> </ul>	<ul style="list-style-type: none"> <li>● Same disadvantages as electrical resistance blocks</li> </ul>
Tensiometers	<ul style="list-style-type: none"> <li>● Inexpensive</li> <li>● Good for long-term monitoring; can be interfaced with automatic data recorders</li> <li>● Do not require external power source</li> <li>● Accurate</li> </ul>	<ul style="list-style-type: none"> <li>● Require emplacement in soil; difficult to emplace in coarse soils or fractured or indurated media</li> <li>● Provide single point data only</li> <li>● Differing surface tension of some organic contaminants may affect accuracy</li> <li>● Time lag in response and problems with hysteresis</li> <li>● Fragile; if not used with ethylene glycol (antifreeze), must be removed in freezing weather</li> </ul>



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### ATTACHMENT B

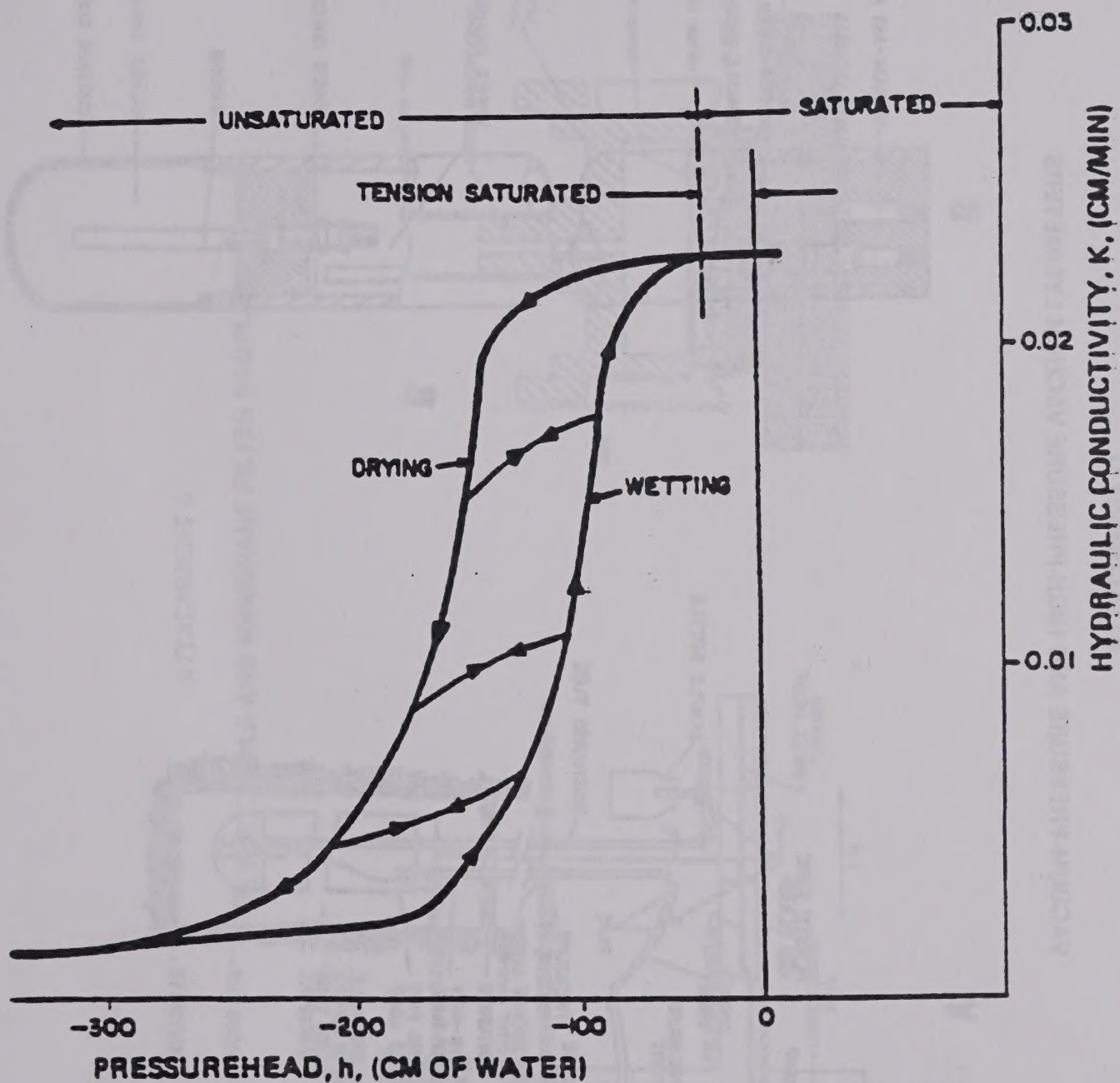
#### SOIL-WATER CHARACTERISTIC CURVES FOR WETTING AND DRYING, ILLUSTRATING HYSTERESIS





## ATTACHMENT C

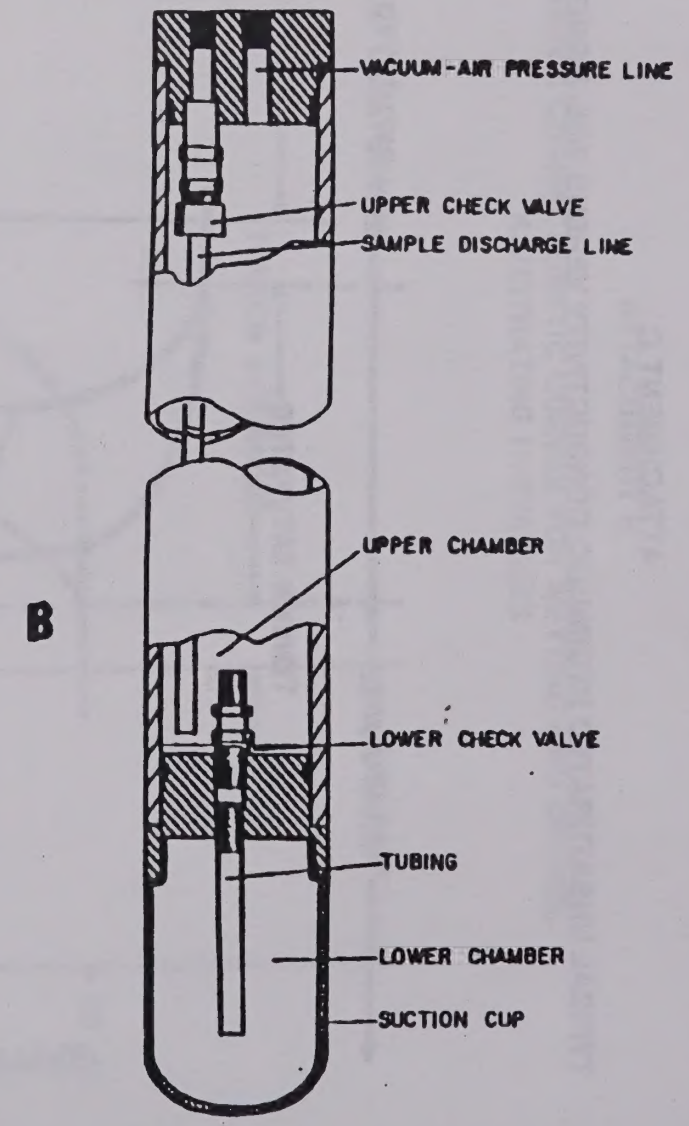
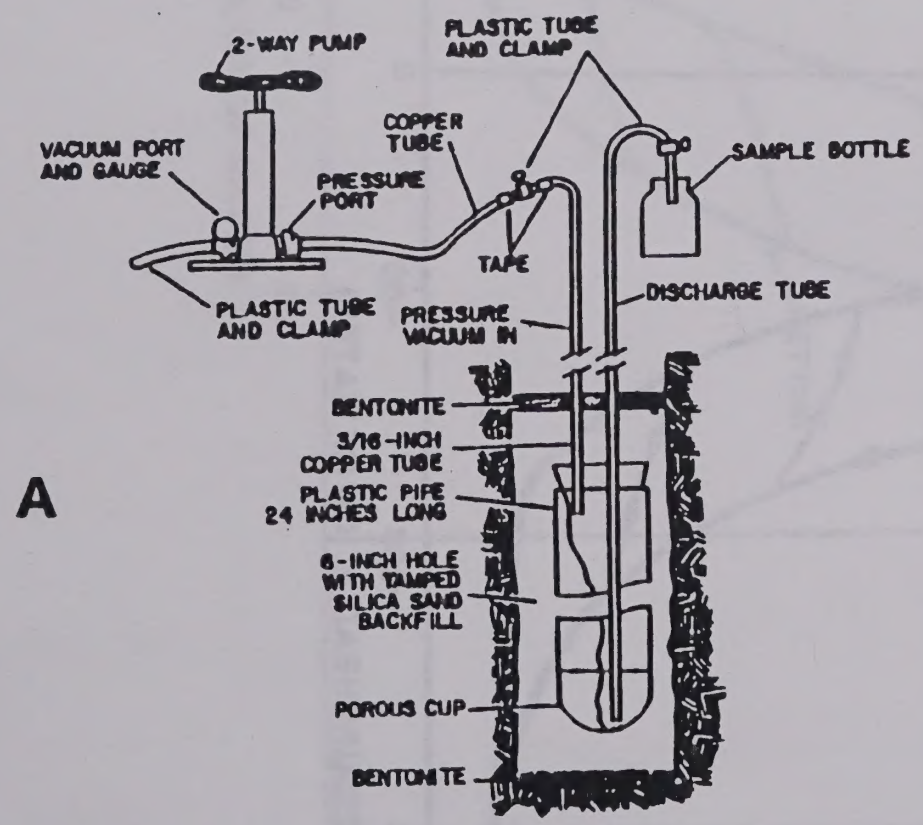
## TYPICAL UNSATURATED HYDRAULIC CONDUCTIVITY VERSUS SOIL MOISTURE CURVE





# ATTACHMENT D

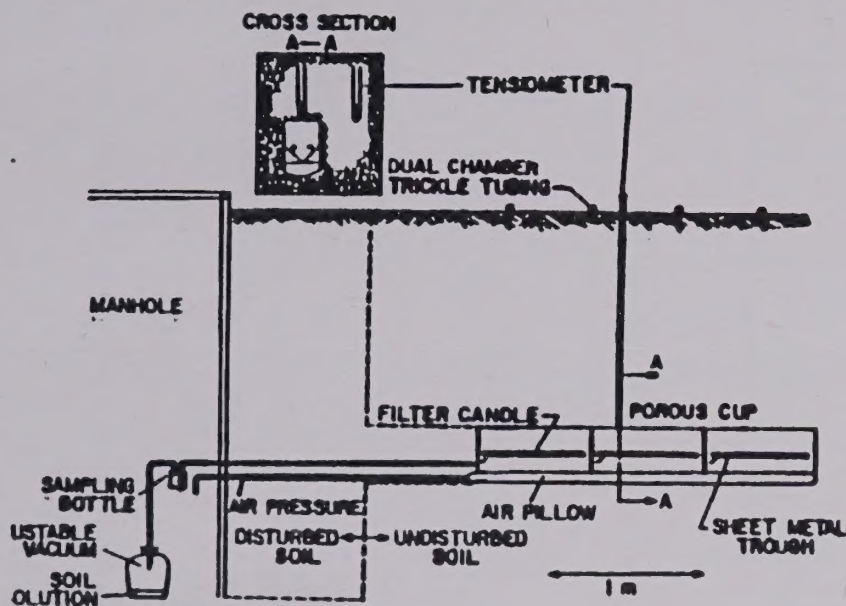
## VACUUM-PRESSURE AND HIGH-PRESSURE VACUUM LYSIMETERS



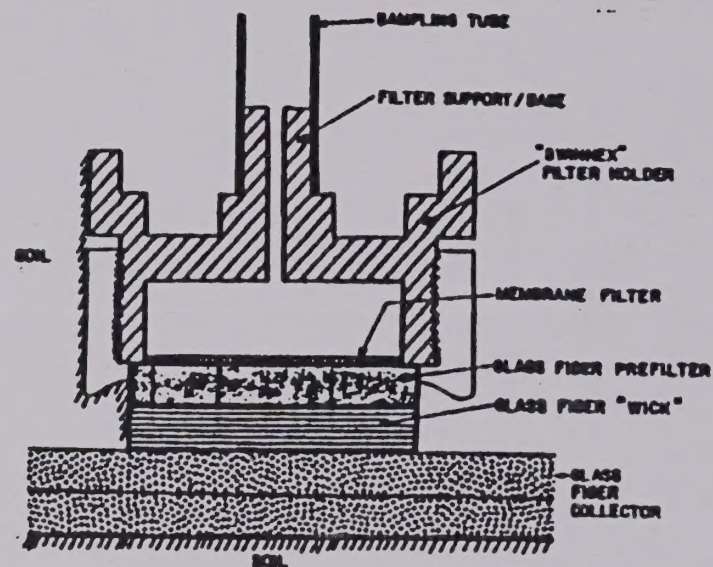


## ATTACHMENT E

### FILTER CANDLE AND MEMBRANE FILTER SAMPLERS



**A**



**B**



# FIG. 1

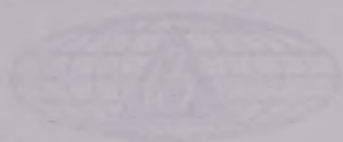
FIG. 1 is a perspective view of the device in accordance with the present invention.



# FIG. 2

FIG. 2 is a perspective view of the device in accordance with the present invention, showing the internal components.





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# STANDARD OPERATING PROCEDURES

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Approved: GAB Environmental, Inc.	
Prepared: Earth Sciences Department	
Reviewed: D. Schenck	

## NONHAZARDOUS SAMPLE HANDLING

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Applicability  
B&R Environmental, NE

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Earth Sciences Department

Subject  
NON-RADIOLOGICAL SAMPLE HANDLING

Approved  
D. Senovich

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## 1.0 PURPOSE

The purpose of this Standard Operating Procedure (SOP) is to provide information on sample preservation, packaging, and shipping procedures to be used in handling environmental samples submitted for chemical constituent, biological, or geotechnical analysis. Sample chain-of-custody procedures and other aspects of field documentation are addressed in SOP SA-6.3. Sample identification is addressed in SOP CT-04.

## 2.0 SCOPE

This procedure:

- Describes the appropriate containers to be used for samples depending on the analyses to be performed, and the steps necessary to preserve the samples when shipped off site for chemical analysis.
- Provides instruction for sample packaging and shipping in accordance with current U.S. Department of Transportation (DOT) regulations.

## 3.0 GLOSSARY

Hazardous Material - A substance or material which has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and which has been so designated. Under 49 CFR, the term includes hazardous substances, hazardous wastes, marine pollutants, and elevated temperature materials, as well as materials designated as hazardous under the provisions of §172.101 and §172.102 and materials that meet the defining criteria for hazard classes and divisions in Part 173.

Hazardous Waste - Any substance listed in 40 CFR, Subpart D (y261.30 et seq.), or otherwise characterized as ignitable, corrosive, reactive, or toxic (as defined by Toxicity Characteristic Leaching Procedure, TCLP, analysis) as specified under 40 CFR, Subpart C (y261.20 et seq.), that would be subject to manifest requirements specified in 40 CFR 262. Such substances are defined and regulated by EPA.

Marking - A descriptive name, identification number, instructions, cautions, weight, specification or UN marks, or combination thereof required on outer packaging of hazardous materials.

n.o.i - Not otherwise indicated (may be used interchangeably with n.o.s.).

n.o.s. - Not otherwise specified.

ORM - Other regulated material (see DOT 49 CFR 173.144).

Packaging - A receptacle and any other components or materials necessary for compliance with the minimum packaging requirements of 49 CFR 174, including containers (other than freight containers or overpacks), portable tanks, cargo tanks, tank cars, and multi-unit tank-car tanks to perform a containment function in conformance with the minimum packaging requirements of 49 CFR 173.24(a) & (b).

Placard - Color-coded, pictorial sign which depicts the hazard class symbol and name and which is placed on the side of a vehicle transporting certain hazardous materials.



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#### Common Preservatives:

- Hydrochloric Acid - HCl
- Sulfuric Acid - H<sub>2</sub>SO<sub>4</sub>
- Nitric Acid - HNO<sub>3</sub>
- Sodium Hydroxide - NaOH

#### Other Preservatives

- Zinc Acetate
- Sodium Thiosulfate - Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>

Normality (N) - Concentration of a solution expressed as equivalent per liter, an equivalent being the amount of a substance containing 1 gram-atom of replaceable hydrogen or its equivalent. Thus, a one-molar solution of HCl, containing 1 gram-atom of H, is "one normal," whereas a one-molar solution of H<sub>2</sub>SO<sub>4</sub>, containing 2 gram-atoms of H, is "two normal."

Reportable Quantity (RQ) - For the purposes of this SOP, means the quantity specified in column 3 of the Appendix to DOT 49 CFR §172.101 for any material identified in column 1 of the appendix. A spill greater than the amount specified must be reported to the National Response Center.

Sample - A sample is physical evidence collected from a facility or the environment, which is representative of conditions at the location and time of collection.

### 4.0 RESPONSIBILITIES

Field Operations Leader - Directly responsible for the bottling, preservation, labeling, packaging, shipping, and custody of samples up to and including release to the shipper.

Field Samplers - Responsible for initiating the Chain-of-Custody Record (per SOP SA-6.3), implementing the packaging and shipping requirements, and maintaining custody of samples until they are relinquished to another custodian or to the common carrier.

### 5.0 PROCEDURES

Sample identification, labeling, documentation, and chain-of-custody are addressed by SOP SA-6.3.

#### 5.1 Sample Containers

Different types of chemicals react differently with sample containers made of various materials. For example, trace metals adsorb more strongly to glass than to plastic, whereas many organic chemicals may dissolve various types of plastic containers. Attachments A and B show proper containers (as well as other information) per 40 CFR 136. In general, the sample container shall allow approximately 5-10 percent air space ("ullage") to allow for expansion/vaporization if the sample warms during transport. However, for collection of volatile organic compounds, head space shall be omitted. The analytical laboratory will generally provide certified-clean containers for samples to be analyzed for chemical constituents. Shelby tubes or other sample containers are generally provided by the driller for samples requiring geotechnical analysis. Sufficient lead time shall be allowed for a delivery of bottle orders. Therefore, it is critical to use the correct container to maintain the integrity of the sample prior to analysis.



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Once opened, the container must be used at once for storage of a particular sample. Unused but opened containers are to be considered contaminated and must be discarded; because of the potential for introduction of contamination, they cannot be reclosed and saved for later use. Likewise, any unused containers which appear contaminated upon receipt, or which are found to have loose caps or a missing Teflon liner (if required for the container), shall be discarded.

## 5.2 Sample Preservation

Many water and soil samples are unstable and therefore require preservation to prevent changes in either the concentration or the physical condition of the constituent(s) requiring analysis. Although complete and irreversible preservation of samples is not possible, preservation does retard the chemical and biological changes that inevitably take place after the sample is collected. Preservation techniques are usually limited to pH control, chemical addition(s), and refrigeration/ freezing (certain biological samples only).

### 5.2.1 Overview

The preservation techniques to be used for various analytes are listed in Attachments A and B. Reagents required for sample preservation will either be added to the sample containers by the laboratory prior to their shipment to the field or be added in the field (in a clean environment). Only high purity reagents shall be used for preservation. In general, aqueous samples of low-concentration organics (or soil samples of low- or medium-concentration organics) are cooled to 4°C. Medium-concentration aqueous samples and high-hazard organics samples are typically not preserved. Low-concentration aqueous samples for metals are acidified with HNO<sub>3</sub>, whereas medium-concentration and high-hazard aqueous metal samples are not preserved. Low- or medium-concentration soil samples for metals are cooled to 4°C, whereas high-hazard samples are not preserved.

The following subsections describe the procedures for preparing and adding chemical preservatives. Attachments A and B indicate the specific analytes which require these preservatives.

### 5.2.2 Preparation and Addition of Reagents

Addition of the following acids or bases may be specified for sample preservation; these reagents shall be analytical reagent (AR) grade or purer and shall be diluted to the required concentration with deionized water before field sampling commences. To avoid uncontrolled reactions, be sure to Add Acid to water (not vice versa). A dilutions guide is provided below.

Acid/Base	Dilution	Concentration	Estimated Amount Required for Preservation
Hydrochloric Acid (HCl)	1 part concentrated HCl: 1 part double-distilled, deionized water	6N	5-10 mL
Sulfuric Acid (H <sub>2</sub> SO <sub>4</sub> )	1 part concentrated H <sub>2</sub> SO <sub>4</sub> : 1 part double-distilled, deionized water	18N	2 - 5 mL
Nitric Acid (HNO <sub>3</sub> )	Undiluted concentrated HNO <sub>3</sub>	16N	2 - 5 mL
Sodium Hydroxide (NaOH)	400 grams solid NaOH dissolved in 870 mL double-distilled, deionized water; yields 1 liter of solution	10N	2 mL



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The amounts required for preservation shown in the above table assumes proper preparation of the preservative and addition of the preservative to one liter of aqueous sample (assuming that the sample is initially at pH 7, is poorly buffered, and does not contain particulate matter; as these conditions vary, more preservative may be required). Consequently, the final sample pH must be checked using narrow-range pH paper, as described in the generalized procedure detailed below:

- Pour off 5-10 mL of sample into a dedicated, clean container. Use some of this sample to check the initial sample pH using wide range (0-14) pH paper. Never dip the pH paper into the sample; always apply a drop of sample to the pH paper using a clean stirring rod or pipette.
- Add about one-half of the estimated preservative required to the original sample bottle. Cap and invert gently several times to mix. Check pH (as described above) using medium range pH paper (pH 0-6 or pH 7.5-14, as applicable).
- Cap sample bottle and seal securely.

Additional considerations are discussed below:

- To test if ascorbic acid must be used to remove oxidizing agents present in the sample before it can be properly preserved, place a drop of sample on KI-starch paper. A blue color indicates the need for ascorbic acid addition.

If required, add a few crystals of ascorbic acid to the sample and retest with the KI-starch paper. Repeat until a drop of sample produces no color on the KI-starch paper. Then add an additional 0.6 grams of ascorbic acid per each liter of sample volume.

Continue with proper base preservation of the sample as described, generally, above.

- Samples for sulfide analysis must be treated by the addition of 4 drops (0.2 mL) of 2N zinc acetate solution per 100 ml of sample.

The 2N zinc acetate solution is made by dissolving 220 grams of zinc acetate in 870 mL of double-distilled, deionized water to make 1 liter of solution.

The sample pH is then raised to 9 using the NaOH preservative.

- To test if sodium thiosulfate must be added to remove residual chlorine from a sample, test the sample for residual chlorine using a field test kit especially made for this purpose.

If residual chlorine is present, add 0.08 grams of sodium thiosulfate per liter of sample to remove the residual chlorine.

Continue with proper acidification of the sample as described, generally, above.

For biological samples, 10% buffered formalin or isopropanol may also be required for preservation. Questions regarding preservation requirements should be resolved through communication with the laboratory before sampling begins.



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### 5.3 Field Filtration

At times, field-filtration may be required to provide for the analysis of dissolved chemical constituents. Field-filtration must be performed prior to the preservation of samples as described above. General procedures for field filtration are described below:

- The sample shall be filtered through a non-metallic, 0.45-micron membrane filter, immediately after collection. The filtration system shall consist of dedicated filter canister, dedicated silicon tubing, and a peristaltic pump with pressure or vacuum pumping squeeze action (since the sample is filtered by mechanical peristalsis, the sample travels only through the tubing).
- To perform filtration, thread the silicon tubing through the peristaltic pump head. Attach the filter canister to the discharge end of the silicon tubing (note flow direction arrow); attach the aqueous sample container to the intake end of the silicon tubing. Turn the peristaltic pump on and perform filtration.
- Continue by preserving the filtrate (contained in the filter canister), as applicable and generally described above.

### 5.4 Sample Packaging and Shipping

Samples collected for shipment from a site shall be classified as either environmental or hazardous material samples. Samples from drums containing materials other than Investigative Derived Waste (IDW) and samples obtained from waste piles or bulk storage tanks are generally shipped as hazardous materials. A distinction must be made between the two types of samples in order to:

- Determine appropriate procedures for transportation of samples (if there is any doubt, a sample shall be considered hazardous and shipped accordingly.)
- Protect the health and safety of transport and laboratory personnel receiving the samples (special precautions are used by the shipper and at laboratories when hazardous materials are received.)

Detailed procedures for packaging environmental and hazardous material samples are outlined in the remainder of this section.

#### 5.4.1 Environmental Samples

Environmental samples are packaged as follows:

- Place sample container, properly identified and with lid securely fastened in a plastic bag (e.g. Ziploc baggie), and seal the bag.
- Place sample in a cooler constructed of sturdy material which has been lined with a large, plastic (e.g. "garbage" bag).
- Pack with enough noncombustible, absorbent, cushioning materials such as vermiculite (shoulders of bottles must be iced if required) to minimize the possibility of the container breaking.



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- If cooling is required (see Attachments A and B), double-bag ice in Ziploc baggies and place around container shoulders, and on top of absorbent packing material (minimum of 8 pounds of ice for a medium-size cooler).
- Seal (i.e., tape or tie top in knot) large liner bag.
- The original (top, signed copy) and extra carbonless copies of the COC form shall be placed inside a large Ziploc-type bag and taped inside the lid of the shipping cooler. If multiple coolers are sent but are included on one COC form, the COC form should be sent with the first cooler. The COC form should then state how many coolers are included with that shipment.
- Close and seal outside of cooler as described in SOP SA-6.3. Signed custody seals must be used.

Coolers must be marked as containing "Environmental Samples." The appropriate side of the container must be marked "This End Up" and arrows placed appropriately. No DOT marking or labeling is required; there are no DOT restrictions on mode of transportation.

#### 5.4.2 Determination of Shipping Classification for Hazardous Material Samples

Samples not determined to be environmental samples, or samples known or expected to contain hazardous materials, must be considered hazardous material samples and transported according to the requirements listed below.

##### 5.4.2.1 Known Substances

If the substance in the sample is known or can be identified, package, mark, label, and ship according to the specific instructions for that material (if it is listed) in the DOT Hazardous Materials Table, 49 CFR 172.101. (DOT Guide for shippers can be found in Attachment D of this document.)

To determine the proper shipping name, use the following steps to help locate the shipping name on the Hazardous Materials Table, DOT 49 CFR 172.101.

1. Look first for the chemical or technical name of the material, for example, ethyl alcohol. Note that many chemicals have more than one technical name, for example, perchloroethylene (not listed in 172.101) is listed as tetrachloroethylene (listed 172.101). It may be useful to consult a chemist for all possible technical names a material can have. If your material is not listed by its technical name, then . . .
2. Look for the chemical family name. For example, pentyl alcohol is not listed but the chemical family name is: alcohol, n.o.s. (not otherwise specified). If the chemical family name is not listed, then . . .
3. Look for a generic name based on end use. For example, Paint, n.o.s or Fireworks, n.o.s. If a generic name based on end use is not listed, then . . .
4. Look for a generic family name based on end use, for example, drugs, n.o.s. or cosmetics, n.o.s. Finally, if your material is not listed by a generic family name but you suspect or know the material is hazardous because it meets the definition of one or more hazardous classes, then . . .



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5. You will have to use the general hazard class for a proper shipping name. For example, Flammable Liquid, n.o.s. or Oxidizer, n.o.s.

#### 5.4.2.2 Unknown Substances

For samples of hazardous substances of unknown content, select the appropriate transportation category according to the DOT hazardous materials classification of a material having more than one hazard. This procedure is outlined in DOT Regulation 49 CFR 173.2a. (This can be found in Attachment C of this SOP.)

The correct shipping classification for an unknown sample is selected through a process of elimination, as outlined in DOT Regulation 49 CFR 172.101(c)(11). By using the provisions in this paragraph, the proper shipping name and description will be determined. A step-by-step guide is provided by the Department of Transportation (DOT) and can be found in Attachment D of this SOP.

#### 5.4.3 Packaging and Shipping of Samples Classified as Flammable Liquid (or Solid)

##### 5.4.3.1 Packaging

Applying the word "flammable" to a sample does not imply that it is in fact flammable. The word prescribes the class of packaging according to DOT regulations.

1. Containerize sample as required (see Attachments A and B). To prevent leakage, fill container no more than 90 percent full. Seal lid with teflon tape or wire.
2. Complete sample label and attach securely to sample container.
3. Seal container and place in 2-mil-thick (or thicker) polyethylene bag (e.g., Ziploc baggie), one sample per bag. Position sample identification label so that it can be read through bag. Seal bag.
4. For soil jars, place sealed bag inside metal can (available from laboratory or laboratory supplier) and cushion it with enough noncombustible, absorbent material (for example, vermiculite or diatomaceous earth) between the bottom and sides of the can and bag to prevent breakage and absorb leakage. Pack one bag per can. Use clips, tape, or other positive means to hold can lid securely, tightly and permanently. Mark can as indicated in Paragraph 1 of Section 5.3.4.2, below. Single 1-gallon bottles do not need to be placed in metal cans.
5. Place one or more metal cans (or a single 1-gallon bottle) into a strong outside container, such as a metal picnic cooler or a DOT-approved fiberboard box. Surround cans (or bottle) with noncombustible, absorbent cushioning materials for stability during transport. The absorbent material should be able to absorb the entire contents of the container. Mark container as indicated in Paragraph 2 below.

##### 5.4.3.2 Marking/Labeling

1. Use abbreviations only where specified. Place the following information, either hand-printed or in label form, on the metal can (or 1-gallon bottle):
  - Laboratory name and address.



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- Proper shipping name from the hazardous materials table (DOT Regulation CFR 49 172.101). Example: "Flammable Liquid, n.o.s. UN1993" or "Flammable Solid, n.o.s. UN1325." This will include packing group (see Section 5.3.4.2, No. 2.)

Not otherwise specified (n.o.s) is not used if the flammable liquid (or solid) is identified. If identified, the name of the specific material is listed before the category (for example, Acetone, Flammable Liquid), followed by its appropriate UN number found in the DOT Hazardous Materials table (49 CFR 172.101).

2. Determine packing group. The packing group is part of the proper shipping name and must be included on the shipping papers in the description section.

- I. Most Hazardous
- II. Medium Hazard
- III. Least Hazardous

The packing group will be listed in the hazardous materials table, column 5.

3. Place all information on outside shipping container as on can (or bottle), specifically:

- Proper shipping name
- UN or NA number
- Proper label(s)
- Addressee and sender

Place the following labels on the outside shipping container: "Cargo Aircraft Only" and DOT label such as: "Flammable Liquid" (or "Flammable Solid"). "Dangerous When Wet" label shall be used if the Flammable Solid has not been exposed to a wet environment. "Laboratory Samples" and "THIS SIDE UP" or "THIS END UP" shall also be marked on the top of the outside container, and upward-pointing arrows shall be placed on all four sides of the container.

#### 5.4.3.3 Shipping Papers

1. Use abbreviations only where specified. Complete the carrier-provided bill of lading and sign certification statement. Provide the following information in the order listed (one form may be used for more than one exterior container):

- Proper shipping name. (Example: "Flammable Liquid, n.o.s. UN1993" or "Flammable Solid, n.o.s. UN1325 Packing Group I, II, III").
- "Limited Quantity" (or "Ltd. Qty."). (See No. 3, below.)
- "Cargo Aircraft Only."
- Net weight (wt) or net volume (vol), just before or just after "Flammable Liquid, n.o.s." or "Flammable Solid, n.o.s.," by item, if more than one metal can is inside an exterior container.
- "Laboratory Samples" (if applicable).



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2. Include Chain-of-Custody Record, properly executed in outside container; use custody seals.

3. "Limited Quantity" means the maximum amount of a hazardous material for which there is a specific labeling or packaging exception (DOT CFR 49 171.8). This may mean that packages are exempted from labeling requirements. To determine if your sample meets the Limited Quantity Exception, refer to DOT Regulation CFR 49 Subpart C 173.50 through 173.156. First, determine the proper classification and shipping name for the material; then refer to the exception requirements for that particular class of material beginning with 173.50.

Example: "Flammable Liquid n.o.s. UN1993 Packing Group 1." The outer package can weigh no more than 66 pounds gross weight. The inner package or container can weigh no more than 0.1 gallon net capacity for each container.

To determine whether the material can be shipped as a "Limited Quantity," you must check the specific requirement for that class of material.

#### 5.4.3.4 Transportation

1. The majority of unknown hazardous substance samples will be classified as flammable liquids. The samples will be transported by rented or common carrier truck, railroad, or express overnight package services. Do not transport samples on any passenger-carrying air transport system, even if the system has cargo-only aircraft. DOT regulations permit regular airline cargo-only aircraft, but difficulties with most suggest avoiding them. Instead, ship by airline carriers that carry only cargo. If unsure of what mode of transportation to use, consult the FOL or Project Manager.
2. For transport by government-owned vehicle, including aircraft, DOT regulations do not apply. However, procedures described above, with the exception of execution of the bill of lading with certification, shall still be followed.
3. Use the hazardous materials shipping check list (Attachment E) as a guidance to ensure that all sample-handling requirements are satisfied.
4. In some cases, various materials may react if they break during shipment. To determine if you are shipping such materials, refer to the DOT compatibility chart in Attachment F.

#### 5.5 Shipment of Lithium Batteries

Monitoring well data are analyzed using either the Hermit SE 1000 or the Hermit SE 2000 environmental data logger. These instruments are powered by lithium batteries. The Department of Transportation has determined that lithium batteries are a hazardous material and are to be shipped using the following information:

- 
- <sup>1</sup> Note: If you are unsure as how to ship the sample (hazardous or environmental sample), contact the FOL or Project Manager so that a decision can be made as to the proper shipping practices. The DOT penalties for improper shipment of a hazardous material are stringent and may include a prison term for intentional violations.



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- Product Designation
  - Hermit SE 1000
  - Hermit SE 2000
- DOT Proper Shipping Name
  - Lithium batteries, contained in equipment, UN3091
- Classification or Division
  - Class 9

Shipment of equipment containing lithium batteries must be accompanied by shipping papers completed as indicated in Attachment G. The instrument will be shipped by Federal Express as a Hazardous Material. Place the instrument in the same container in which it was received. This container or case is a DOT-approved shipping container. For Federal Express procedures to ship hazardous materials, call 1-800-238-5355, extension 922-1666. In most cases, the return shipping papers and DOT labels will be shipped to you from the company warehouse or the vendor. An example of the types of labels used for shipment and the wording are shown in Attachment G. These labels will be attached to the outside container with the following wording:

- Lithium Batteries Contained in Equipment
  - UN-3091
  - Shipped Under CA-9206009

## 6.0 REFERENCES

American Public Health Association, 1981. Standard Methods for the Examination of Water and Wastewater, 15th Edition. APHA, Washington, D.C.

U.S. Department of Transportation, 1993. Hazardous Materials Regulations, 49 CFR 171-177.

U.S. EPA, 1984. "Guidelines Establishing Test Procedures for the Analysis of Pollutants under Clean Water Act." Federal Register, Volume 49 (209), October 26, 1984, p. 43234.

U.S. EPA, 1979. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020, U.S. EPA-EMSL, Cincinnati, Ohio.



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## ATTACHMENT A

### GENERAL SAMPLE CONTAINER AND PRESERVATION REQUIREMENTS

Sample Type and Concentration	Container <sup>(1)</sup>	Sample Size	Preservation <sup>(2)</sup>	Holding Time <sup>(2)</sup>
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#### WATER

Organics (GC&GC/MS)	VOC Low	Borosilicate glass	2 x 40 mL	Cool to 4°C HCl to $\leq 2$	14 days <sup>(9)</sup>
	Extractables (Low) SVOCs and pesticide/PCBs)	Amber glass	2x2 L or 4x1 L	Cool to 4°C	7 days to extraction; 40 days after extraction
	Extractables (Medium) SVOCs and pesticide/PCBs)	Amber glass	2x2 L or 4x1 L	None	7 days to extraction; 40 days after extraction
Inorganics	Metals Low	High-density polyethylene	1 L	HNO <sub>3</sub> to pH $\leq 2$	6 months (Hg-28 days)
	Medium	Wide-mouth glass	16 oz.	None	6 months
	Cyanide Low	High-density polyethylene	1 L	NaOH to pH > 12	14 days
	Cyanide Medium	Wide-mouth glass	16 oz.	None	14 days
Organic/ Inorganic	High Hazard	Wide-mouth glass	8 oz.	None	14 days

#### SOIL

Organics (GC&GC/MS)	VOC	Wide-mouth glass with teflon liner	2 x 4 oz.	Cool to 4°C	14 days
	Extractables (Low) SVOCs and pesticides/PCBs)	Wide-mouth glass	8 oz.	Cool to 4°C	14 days to extraction; 40 days after extraction
	Extractables (Medium) SVOCs and pesticides/PCBs)	Wide-mouth glass	8 oz.	Cool to 4°C	14 days to extraction; 40 days after extraction
Inorganics	Low/Medium	Wide-mouth glass	8 oz.	Cool to 4°C	6 months (Hg - 28 days) Cyanide (14 days)
Organic/ Inorganic	High Hazard	Wide-mouth glass	8 oz.	None	NA
Dioxin/Furan	All	Wide-mouth glass	4 oz.	None	7 days until extraction; 40 days after extraction
TCLP	All	Wide-mouth glass	8 oz.	None	7 days until preparation; analysis as per fraction

#### AIR

Volatile Organics	Low/Medium	Charcoal tube - 7 cm long, 6 mm OD, 4 mm ID	100 L air	Cool to 4°C	5 days recommended
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<sup>(1)</sup> All glass containers should have Teflon cap liners or septa.

<sup>(2)</sup> See Attachment E. Preservation and maximum holding time allowances per 40 CFR 136.



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## ATTACHMENT B

### ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES

Parameter Number/Name	Container <sup>(1)</sup>	Preservation <sup>(2)(3)</sup>	Maximum Holding Time <sup>(4)</sup>
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#### INORGANIC TESTS:

Acidity	P, G	Cool, 4°C	14 days
Alkalinity	P, G	Cool, 4°C	14 days
Ammonia - Nitrogen	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Biochemical Oxygen Demand (BOD)	P, G	Cool, 4°C	48 hours
Bromide	P, G	None required	28 days
Chemical Oxygen Demand (COD)	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Chloride	P, G	None required	28 days
Chlorine, Total Residual	P, G	None required	Analyze immediately
Color	P, G	Cool, 4°C	48 hours
Cyanide, Total and Amenable to Chlorination	P, G	Cool, 4°C; NaOH to pH 12; 0.6 g ascorbic acid <sup>(5)</sup>	14 days <sup>(6)</sup>
Fluoride	P	None required	28 days
Hardness	P, G	HNO <sub>3</sub> to pH 2; H <sub>2</sub> SO <sub>4</sub> to pH 2	6 months
Total Kjeldahl and Organic Nitrogen	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Nitrate - Nitrogen	P, G	None required	48 hours
Nitrate-Nitrite - Nitrogen	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Nitrite - Nitrogen	P, G	Cool, 4°C	48 hours
Oil & Grease	G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Total Organic Carbon (TOC)	P, G	Cool, 4°C; HCl or H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Orthophosphate	P, G	Filter immediately; Cool, 4°C	48 hours
Oxygen, Dissolved-Probe	G Bottle & top	None required	Analyze immediately
Oxygen, Dissolved-Winkler	G Bottle & top	Fix on site and store in dark	8 hours
Phenols	G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Phosphorus, Total	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Residue, Total	P, G	Cool, 4°C	7 days
Residue, Filterable (TDS)	P, G	Cool, 4°C	7 days
Residue, Nonfilterable (TSS)	P, G	Cool, 4°C	7 days
Residue, Settleable	P, G	Cool, 4°C	48 hours
Residue, Volatile (Ash Content)	P, G	Cool, 4°C	7 days
Silica	P	Cool, 4°C	28 days
Specific Conductance	P, G	Cool, 4°C	28 days
Sulfate	P, G	Cool, 4°C	28 days



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**ATTACHMENT B  
ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES,  
AND HOLDING TIMES  
PAGE TWO**

Parameter Number/Name	Container <sup>(1)</sup>	Preservation <sup>(2)(3)</sup>	Maximum Holding Time <sup>(4)</sup>
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**INORGANIC TESTS (Cont'd):**

Sulfide	P, G	Cool, 4°C; add zinc acetate plus sodium hydroxide to pH 9	7 days
Sulfite	P, G	None required	Analyze immediately
Turbidity	P, G	Cool, 4°C	48 hours

**METALS:<sup>(7)</sup>**

Chromium VI (Hexachrome)	P, G	Cool, 4°C	24 hours
Mercury (Hg)	P, G	HNO <sub>3</sub> to pH 2	28 days
Metals, except Chromium VI and Mercury	P, G	HNO <sub>3</sub> to pH 2	6 months

**ORGANIC TESTS:<sup>(8)</sup>**

Purgeable Halocarbons	G. Teflon-lined septum	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	14 days
Purgeable Aromatic Hydrocarbons	G. Teflon-lined septum	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> HCl to pH 2 <sup>(9)</sup>	14 days
Acrolein and Acrylonitrile	G. Teflon-lined septum	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> adjust pH to 4-5 <sup>(10)</sup>	14 days
Phenols <sup>(11)</sup>	G. Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction
Benzidines <sup>(11), (12)</sup>	G. Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction <sup>(13)</sup>
Phthalate esters <sup>(11)</sup>	G. Teflon-lined cap	Cool, 4°C	7 days until extraction; 40 days after extraction
Nitrosamines <sup>(11), (14)</sup>	G. Teflon-lined cap	Cool, 4°C; store in dark; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction
PCBs <sup>(11)</sup>	G. Teflon-lined cap	Cool, 4°C	7 days until extraction; 40 days after extraction
Nitroaromatics & Isophorone <sup>(11)</sup>	G. Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> ; store in dark	7 days until extraction; 40 days after extraction
Polynuclear Aromatic Hydrocarbons (PAHs) <sup>(11), (14)</sup>	G. Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> ; store in dark	7 days until extraction; 40 days after extraction
Haloethers <sup>(11)</sup>	G. Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction
Dioxin/Furan (TCDD/TCDF) <sup>(11)</sup>	G. Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction



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**ATTACHMENT B  
ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES,  
AND HOLDING TIMES  
PAGE THREE**

Parameter Number/Name	Container <sup>(1)</sup>	Preservation <sup>(2)(3)</sup>	Maximum Holding Time <sup>(4)</sup>
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**RADIOLOGICAL TESTS:**

1-5 Alpha, beta and radium	P, G	HNO <sub>3</sub> to pH 2	6 months
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- (1) Polyethylene (P): generally 500 ml or Glass (G): generally 1L
- (2) Sample preservation should be performed immediately upon sample collection. For composite chemical samples each aliquot should be preserved at the time of collection. When use of an automated sampler makes it impossible to preserve each aliquot, then chemical samples may be preserved by maintaining at 4°C until compositing and sample splitting is completed.
- (3) When any sample is to be shipped by common carrier or sent through the United States Mail, it must comply with the Department of Transportation Hazardous Materials Regulations (49 CFR Part 172).
- (4) Samples should be analyzed as soon as possible after collection. The times listed are the maximum times that samples may be held before analysis and still be considered valid. Samples may be held for longer periods only if the permittee, or monitoring laboratory, has data on file to show that the specific types of samples under study are stable for the longer periods, and has received a variance from the Regional Administrator.
- (5) Should only be used in the presence of residual chlorine.
- (6) Maximum holding time is 24 hours when sulfide is present. Optionally, all samples may be tested with lead acetate paper before pH adjustments are made to determine if sulfide is present. If sulfide is present, it can be removed by the addition of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and then NaOH is added to pH 12.
- (7) Samples should be filtered immediately on site before adding preservative for dissolved metals.
- (8) Guidance applies to samples to be analyzed by GC, LC, or GC/MS for specific compounds.
- (9) Sample receiving no pH adjustment must be analyzed within 7 days of sampling.
- (10) The pH adjustment is not required if acrolein will not be measured. Samples for acrolein receiving no pH adjustment must be analyzed within 3 days of sampling.
- (11) When the extractable analytes of concern fall within a single chemical category, the specified preservative and maximum holding times should be observed for optimum safeguard of sample integrity. When the analytes of concern fall within two or more chemical categories, the sample may be preserved by cooling to 4°C, reducing residual chlorine with 0.008% sodium thiosulfate, storing in the dark, and adjusting the pH to 6-9; samples preserved in this manner may be held for 7 days before extraction and for 40 days after extraction. Exceptions to this optional preservation and holding time procedure are noted in footnote 5 (re: the requirement for thiosulfate reduction of residual chlorine) and footnotes 12, 13 (re: the analysis of benzidine).
- (12) If 1,2-diphenylhydrazine is likely to be present, adjust the pH of the sample to 4.0±0.2 to prevent rearrangement to benzidine.
- (13) Extracts may be stored up to 7 days before analysis if storage is conducted under an inert (oxidant-free) atmosphere.
- (14) For the analysis of diphenylnitrosamine, add 0.008% Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> and adjust pH to 7-10 with NaOH within 24 hours of sampling.
- (15) The pH adjustment may be performed upon receipt at the laboratory and may be omitted if the samples are extracted within 72 hours of collection. For the analysis of aldrin, add 0.008% Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>.



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### ATTACHMENT C

#### DOT HAZARDOUS MATERIAL CLASSIFICATION (49 CFR 173.2a)

1. Radioactive material (except a limited quantity)
2. Division 2.3, Poisonous Gases
3. Division 2.1, Flammable Gas
4. Division 2.2, Nonflammable gas
5. Division 6.1, Poisonous Liquids, Packing Group 1 (poison by inhalation only)
6. Division 4.2, Pyrophoric Material
7. Division 4.1, Self-Reactive Material
8. Class 3, Flammable Liquids\*
9. Class 8, Corrosive Material
10. Division 4.1, Flammable Solid\*
11. Division 4.2, Spontaneously Combustible Materials\*
12. Division 4.3, Dangerous When Wet Materials\*
13. Division 5.1, Oxidizers\*
14. Division 6.1, Poisonous Liquids or Solids (other than Packing Group 1)\*
15. Combustible liquid
16. Class 9, Miscellaneous Hazardous Materials

- \* If a material has or meets the criteria for more than one hazard class, use the precedence of hazardous table on the following page for Classes 3 and 8 and Divisions 4.1, 4.2, 4.3, 5.1, and 6.1. The following table ranks those materials that meet the definition of Classes 3 and 8 and Divisions 4.1, 4.2, 4.3, 5.1, and 6.1.



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## ATTACHMENT C (Continued)

PRECEDENCE OF HAZARD TABLE  
(Hazard Class and Packing Group)

Class	Packing Group	4.2	4.3	5.1 I <sup>(a)</sup>	5.1 II <sup>(a)</sup>	5.1 III <sup>(a)</sup>	6.1 I (Dermal)	6.1 I (Oral)	6.1 II	6.1 III	8 I (Liquid)	8 I (Solid)	8 II (Liquid)	8 II (Solid)	8 III (Liquid)	8 III (Solid)
3	I						3	3	3	3	3	Id	3	Id	3	Id
3	II						3	3	3	3	8	Id	3	Id	3	Id
3	III						6.1	6.1	6.1	3 <sup>(d)</sup>	8	Id	8	Id	3	Id
4.1	II <sup>b</sup>	4.2	4.3	5.1	4.1	4.1	6.1	6.1	4.1	4.1	Id	8	Id	4.1	Id	4.1
4.1	III <sup>b</sup>	4.2	4.3	5.1	4.1	4.1	6.1	6.1	6.1	4.1	Id	8	Id	8	Id	4.1
4.2	II		4.3	5.1	4.2	4.2	6.1	6.1	4.2	4.2	Id	8	Id	4.2	Id	4.2
4.2	III		4.3	5.1	4.2	4.2	6.1	6.1	6.1	4.2	Id	8	Id	8	Id	4.2
4.3	I			5.1	4.3	4.3	6.1	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
4.3	II			5.1	4.3	4.3	6.1	4.3	4.3	4.3	8	8	8	4.3	4.3	4.3
4.3	III			5.1	4.3	4.3	6.1	6.1	6.1	4.3	8	8	8	8	4.3	4.3
5.1	I <sup>a</sup>						5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
5.1	II <sup>a</sup>						6.1	5.1	5.1	5.1	8	8	8	5.1	5.1	5.1
5.1	III <sup>a</sup>						6.1	6.1	6.1	5.1	8	8	8	8	5.1	5.1
6.1	I, Dermal										8	6.1	6.1	6.1	6.1	6.1
6.1	I, Oral										8	6.1	6.1	6.1	6.1	6.1
6.1	II, Inhalation										8	6.1	6.1	6.1	6.1	6.1
6.1	II, Dermal										8	6.1	8	6.1	6.1	6.1
6.1	II, Oral										8	8	8	6.1	6.1	6.1
6.1	III										8	8	8	8	8	8

<sup>(a)</sup> There are at present no established criteria for determining Packing Groups for liquids in Division 5.1. At present, the degree of hazard is to be assessed by analogy with listed substances, allocating the substances to Packing Group I, Great; Group II, Medium; or Group III, Minor Danger.

<sup>(b)</sup> Substances of Division 4.1 other than self-reactive substances.

<sup>(c)</sup> Denotes an impossible combination.

<sup>(d)</sup> For pesticides only, where a material has the hazards of Class 3, Packing Group III, and Division 6.1, Packing Group III, the primary hazard is Division 6.1, Packing Group III.



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## ATTACHMENT D

### GUIDE FOR HAZARDOUS MATERIALS SHIPPERS

**USE OF GUIDE** - This guide is presented as an aid to shippers of hazardous materials. It does not contain or refer to all of the DOT requirements for shipping hazardous materials. For specific details, refer to all of the DOT requirements for shipping hazardous materials, as provided in the Code of Federal Regulations (CFR), Title 49, Transportation, Parts 100-199.

The following is offered as a step-by-step procedure to aid in compliance with the applicable DOT regulations.

**STEP 1 - DETERMINE THE PROPER SHIPPING NAME.** The shipper must determine the proper shipping name of the materials as listed in the Hazardous Materials Table, 49 CFR 172.101, Column (2).

**STEP 2 - DETERMINE THE HAZARD CLASS OR CLASSES.**

- Refer to the Table, 49 CFR 172.101, Column (3), and locate the hazard class of the material.
- If more than one class is shown for the proper shipping name, determine the proper class by definition.
- If the materials have more than one hazard, classify the material based on the order of hazards in 49 CFR 173.2.

**STEP 3 - SELECT THE PROPER IDENTIFICATION NUMBERS.**

- Refer to the Table, 49 CFR 172.101, Column (3a), and select the Identification Number (ID) that corresponds to the proper shipping name and hazard class.
- Enter the ID number(s) on the shipping papers and display them, as required, on packagings, placards and/or orange panels.

**STEP 4 - DETERMINE THE MODE(S) OF TRANSPORT TO ULTIMATE DESTINATION.**

- As a shipper, you must assure yourself that the shipment complies with various modal requirements.
- The modal requirements may affect the following: (1) Packaging; (2) Quantity per Package; (3) Marking; (4) Labeling; (5) Shipping Papers; and (6) Certification.

**STEP 5 - SELECT THE PROPER LABEL(S) AND APPLY AS REQUIRED.**

- Refer to the Table, 49 CFR 172.101, Column (4) for required labels.
- For details on labeling refer to (1) Additional Labels, 49 CFR 172.402; (2) Placement of Labels, 49 CFR 172.406; (3) Packagings (Mixed or Consolidated), 49 CFR 172.404(a) and (h); (4) Packages Containing Samples, 49 CFR 172.402(h); (5) Radioactive Materials, 49 CFR 172.403; and (6) Authorized Label Modifications, 49 CFR 172.405.

**STEP 6 - DETERMINE AND SELECT THE PROPER PACKAGES.**

- Refer to the Table, 49 CFR 172.101, Column (5a) for exceptions and Column (5b) for specification packagings. Consider the following when selecting an authorized package: Quantity per Package; Cushioning Material, if required; Proper Closure and Reinforcement; Proper Pressure; Outage; etc., as required.
- If packaged by a prior shipper, make sure the packaging is correct and in proper condition for transportation.



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**ATTACHMENT D (Continued)**  
**GUIDE FOR HAZARDOUS MATERIALS SHIPPERS**

**STEP 7 - MARK THE PACKAGING (INCLUDING OVERPACKS).**

- Apply the required markings (49 CFR 172.300); Proper shipping name and ID number, when required (49 CFR 172.301); Name and address of Consignee or Consignor (49 CFR 172.306).
- For details and other required markings, see 49 CFR 172.300 through 172.338.

**STEP 8 - PREPARE THE SHIPPING PAPERS.**

- The basic requirements for preparing shipping papers include Proper Shipping Name; Hazard Class; ID Number; Total Quantity; Shipper's Certification; and Emergency Response Telephone Number.
- Make all entries on the shipping papers using the information required and in proper sequence (49 CFR 172.202).

**STEP 9 - CERTIFICATION.**

- Each shipper must certify by printing (manually or mechanically) on the shipping papers that the materials being offered for shipment are properly classified, described, packaged, marked and labeled, and in proper condition for transportation according to the applicable DOT Regulations (49 CFR 172.202).

**STEP 10 - LOADING, BLOCKING, AND BRACING.** When hazardous materials are loaded into the transport vehicle or freight container, each package must be loaded, blocked, and braced in accordance with the requirements for mode of transport.

- If the shipper loads the freight container or transport vehicle, the shipper is responsible for the proper loading, blocking, and bracing of the materials.
- If the carrier does the loading, the carrier is responsible.

**STEP 11 - DETERMINE THE PROPER PLACARD(S).** Each person who offers hazardous materials for transportation must determine that the placarding requirements have been met.

- For Highway, unless the vehicle is already correctly placarded, the shipper must provide the required placard(s) and required ID number(s) (49 CFR 172.506).
- For Rail, if loaded by the shipper, the shipper must placard the rail car if placards are required (49 CFR 172.508).
- For Air and Water shipments, the shipper has the responsibility to apply the proper placards.

**STEP 12 - HAZARDOUS WASTE/HAZARDOUS SUBSTANCE.**

- If the material is classed as a hazardous waste or hazardous substance, most of the above steps will be applicable.
- Pertinent Environmental Protection Agency regulations are found in the Code of Federal Regulations, Title 40, Part 262.

**As a final check and before offering the shipment for transportation, visually inspect your shipment. The shipper should ensure that emergency response information is on the vehicle for transportation of hazardous materials.**

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## ATTACHMENT E

### HAZARDOUS MATERIALS SHIPPING CHECK LIST

#### PACKAGING

1. Check DOT 173.24 for appropriate type of package for hazardous substance.
2. Check for container integrity, especially the closure.
3. Check for sufficient absorbent material in package.
4. Check for sample tags and log sheets for each sample and for chain-of-custody record.

#### SHIPPING PAPERS

1. Check that entries contain only approved DOT abbreviations.
2. Check that entries are in English.
3. Check that hazardous material entries are specially marked to differentiate them from any nonhazardous materials being sent using same shipping paper.
4. Be careful that all hazardous classes are shown for multiclass materials.
5. Check total amounts by weight, quantity, or other measures used.
6. Check that any limited-quantity exemptions are so designated on the shipping paper.
7. Check that certification is signed by shipper.
8. Make certain driver signs for shipment.

#### RCRA MANIFEST

1. Check that approved state/federal manifests are prepared.
2. Check that transporter has the following: valid EPA identification number, valid driver's license, valid vehicle registration, insurance protection, and proper DOT labels for materials being shipped.
3. Check that destination address is correct.
4. Check that driver knows where shipment is going.
5. Check that the driver is aware of emergency procedures for spills and accidents.
6. Make certain driver signs for shipment.
7. Make certain one copy of executed manifest and shipping document is retained by shipper.



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## ATTACHMENT F

## DOT SEGREGATION AND SEPARATION CHART

Class or Division	Notes	1.1- 1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3 gas Zone A*	2.3 gas Zone B*	3	4.1	4.2	4.3	5.1	5.2	6.1 liquids PG-I Zone A*	7	8 liquids only
Explosives . . . . . 1.1 and 1.2	A	*	*	*	*	*	X	X	X	X	X	X	X	X	X	X	X	X	X
Explosives . . . . . 1.3		*	*	*	*	*	X		X	X	X		X	X	X	X	X		X
Explosives . . . . . 1.4		*	*	*	*	*	O		O	O	O		O				O		O
Very insensitive explosives . . . . . 1.5	A	*	*	*	*	*	X	X	X	X	X	X	X	X	X	X	X	X	X
Extremely insensitive explosives . . . . . 1.6		*	*	*	*	*													
Flammable gases . . . . . 2.1		X	X	O	X				X	O							O	O	
Non-toxic, non-flammable gases . . . . . 2.2		X			X														
Poisonous gas - Zone A** . . . . . 2.3		X	X	O	X		X				X	X	X	X	X	X			X
Poisonous gas - Zone B** . . . . . 2.3		X	X	O	X		O				O	O	O	O	O	O			O
Flammable liquids . . . . . 3		X	X	O	X				X	O					O		X		O
Flammable solids . . . . . 4.1		X			X				X	O							X		O
Spontaneously combustible materials . . . . . 4.2		X	X	O	X				X	O							X		X
Dangerous-when-wet materials . . . . . 4.3		X	X		X				X	O							X		O
Oxidizers . . . . . 5.1	A	X	X		X				X	O	O						X		O
Organic peroxides . . . . . 5.2		X	X		X				X	O							X		O
Poisonous liquids PG I - Zone A** . . . . . 6.1		X	X	O	X		O				X	X	X	X	X	X			X
Radioactive materials . . . . . 7		X			X		O												
Corrosive liquids . . . . . 8		X	X	O	X				X	O		O	X	O	O	O	X		

No entry means that the materials are compatible (have no restrictions).

X These materials may not be loaded, transported, or stored together in the same vehicle or facility.

O The materials may not be loaded, transported, or stored together in the same vehicle or facility unless they are separated for 4 feet on all sides.

\* Check the explosives compatibility chart in 49 CFR 179.848(f).

A Ammonium nitrate fertilizers may be stored with Division 1.1 materials

\*\* Denotes inhalation hazardous for poisons; consult field team leader or project manager if you encounter a material in this class before shipment.



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ATTACHMENT G  
LITHIUM BATTERY SHIPPING PAPERS

3224637861

Two completed and signed copies of this Declaration must be handed to the operator.

## WARNING

Failure to comply in all respects with the applicable Dangerous Goods Regulations may be in breach of the applicable law, subject to legal penalties. This Declaration must not, in any circumstances, be completed and/or signed by a consolidator, a forwarder or an IATA cargo agent.

## TRANSPORT DETAILS

This shipment is within the limitations prescribed for:  
(delete non applicable)

Airport of Departure

PASSENGER AIRCRAFT ONLY

CARGO AIRCRAFT ONLY

Airport of Destination:

19CYS

Shipment type: (delete non-applicable)

NON-RADIOACTIVE

~~RADIOACTIVE~~

## NATURE AND QUANTITY OF DANGEROUS GOODS

Dangerous Goods Identification				Quantity and type of packing	Packing Inst.	Authorization
Proper Shipping Name	Class or Division	UN or ID No.	Subsidiary Risk			
LITHIUM BATTERIES CONTAINED IN EQUIPMENT	9	UN3091		1 PLASTIC BOX X 55 GRAMS	912 II	PER CA-9206009

Additional Handling Information

1 HERMIT SERIES DATALOGGER X 55 GRAMS (11 GRAMS/CELL)

I hereby declare that the contents of this consignment are fully and accurately described above by proper shipping name and are classified, packed, marked, and labeled, and are in all respects in the proper condition for transport by air according to the applicable International and National Government Regulations.

Name/Title of Signatory

Place and Date

Signature  
(see warning above)

Emergency Telephone Number (Required for US Origin or Destination Shipments)

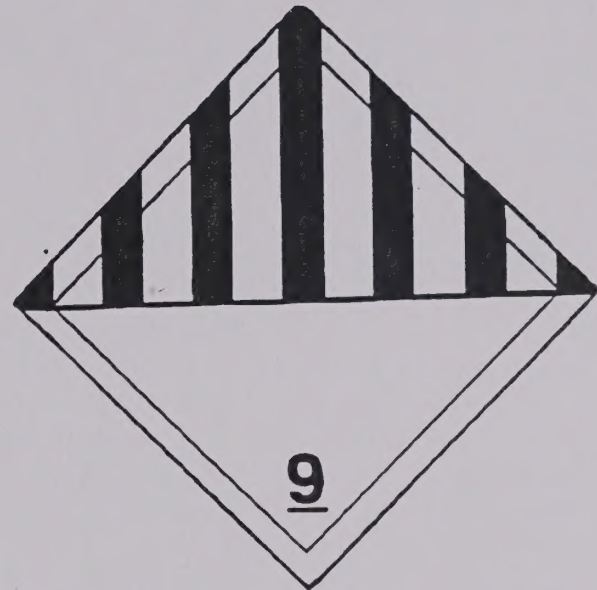
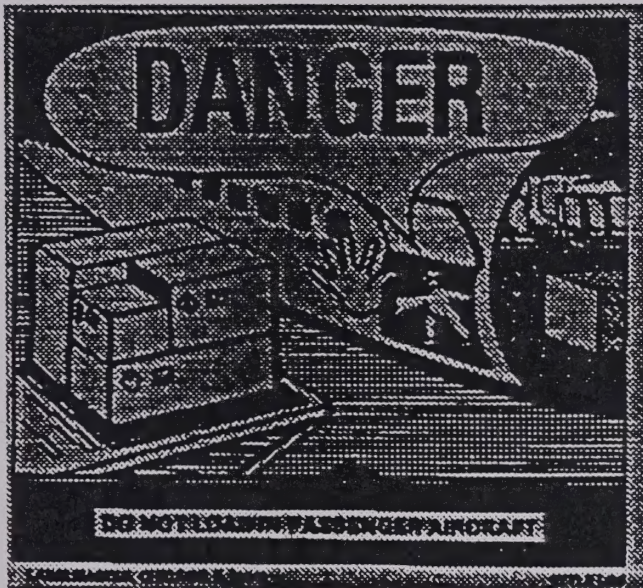
800-535-5053

IF ACCEPTABLE FOR PASSENGER AIRCRAFT, THIS SHIPMENT CONTAINS RADIOACTIVE MATERIAL INTENDED FOR USE IN, OR INCIDENT TO, RESEARCH, MEDICAL DIAGNOSIS, OR TREATMENT.



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**ATTACHMENT G (CONTINUED)  
LITHIUM BATTERY SHIPPING PAPERS**



**LITHIUM BATTERIES CONTAINED  
IN EQUIPMENT.  
UN-3091.  
SHIPPED UNDER CA-9206009**



**ATTACHMENT 2 (CONTINUED) LITHIUM BATTERY SHIPPING INFORMATION**



3224637881

HAZARD INFORMATION

UN 3091

SHIPPED UNDER CA-9206009

IN EQUIPMENT

LITHIUM BATTERIES CONTAINED

IN EQUIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

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FOR SHIPMENT

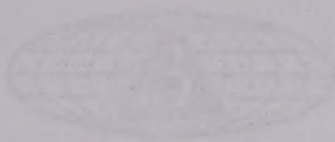
FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT

FOR SHIPMENT





BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

Revision

SA-03

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Revised By

08/01/01

Revised

0

Approved By

SAE Environmental NE

Prepared

Earth Science Department

Subject: FIELD DOCUMENTATION

Reviewed

Q. S. Smith

YSL

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BROWN & ROOT ENVIRONMENTAL

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0

Applicability  
B&R Environmental, NE

Prepared  
Earth Sciences Department

Subject FIELD DOCUMENTATION

Approved  
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## 1.0 PURPOSE

The purpose of this Standard Operating Procedure (SOP) is to identify and designate the field data record forms, logs and reports generally initiated and maintained for documenting Brown & Root Environmental field activities.

## 2.0 SCOPE

Documents presented within this procedure (or equivalents) shall be used for all Brown & Root Environmental field activities, as applicable. Other or additional documents may be required by specific client contracts.

## 3.0 GLOSSARY

None

## 4.0 RESPONSIBILITIES

Project Manager - The Project Manager is responsible for obtaining hardbound, controlled-distribution logbooks (from the appropriate source), as needed. In addition, the Project Manager is responsible for placing all forms used in site activities (i.e., records, field reports, and upon the completion of field work, the site logbook) in the project's central file.

Field Operations Leader (FOL) - The Field Operations Leader is responsible for ensuring that the site logbook, notebooks, and all appropriate forms and field reports illustrated in this guideline (and any additional forms required by the contract) are correctly used, accurately filled out, and completed in the required time-frame.

## 5.0 PROCEDURES

### 5.1 Site Logbook

#### 5.1.1 General

The site logbook is a hard-bound, paginated controlled-distribution record book in which all major onsite activities are documented. At a minimum, the following activities/events shall be recorded (daily) in the site logbook:

- All field personnel present
- Arrival/departure of site visitors
- Arrival/departure of equipment
- Start or completion of borehole/trench/monitoring well installation or sampling activities
- Daily onsite activities performed each day
- Sample pickup information
- Health and Safety issues (level of protection observed, etc.)
- Weather conditions

A site logbook shall be maintained for each project. The site logbook shall be initiated at the start of the first onsite activity (e.g., site visit or initial reconnaissance survey). Entries are to be made for every day that onsite activities take place which involve Brown & Root Environmental or subcontractor personnel. Upon completion of the fieldwork, the site logbook must become part of the project's central file.



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The following information must be recorded on the cover of each site logbook:

- Project name
- Brown & Root Environmental project number
- Sequential book number
- Start date
- End date

Information recorded daily in the site logbook need not be duplicated in other field notebooks (see Section 5.2), but must summarize the contents of these other notebooks and refer to specific page locations in these notebooks for detailed information (where applicable). An example of a typical site logbook entry is shown in Attachment A.

If measurements are made at any location, the measurements and equipment used must either be recorded in the site logbook or reference must be made to the site notebook in which the measurements are recorded (see Attachment A).

All logbook, notebook, and log sheet entries shall be made in indelible ink (black pen is preferred). No erasures are permitted. If an incorrect entry is made, the data shall be crossed out with a single strike mark, and initialed and dated. At the completion of entries by any individual, the logbook pages used must be signed and dated. The site logbook must also be signed by the Field Operations Leader at the end of each day.

#### 5.1.2 Photographs

When movies, slides, or photographs are taken of a site or any monitoring location, they must be numbered sequentially to correspond to logbook entries. The name of the photographer, date, time, site location, site description, and weather conditions must be entered in the logbook as the photographs are taken. A series entry may be used for rapid-sequence photographs. The photographer is not required to record the aperture settings and shutter speeds for photographs taken within the normal automatic exposure range. However, special lenses, films, filters, and other image-enhancement techniques must be noted in the logbook. If possible, such techniques shall be avoided, since they can adversely affect the admissibility of photographs as evidence. Chain-of-custody procedures depend upon the subject matter, type of film, and the processing it requires. Film used for aerial photography, confidential information, or criminal investigation require chain-of-custody procedures. Adequate logbook notation and receipts must be compiled to account for routine film processing. Once processed, the slides of photographic prints shall be consecutively numbered and labeled according to the logbook descriptions. The site photographs and associated negatives must be docketed into the project's central file.

#### 5.2 Site Notebooks

Key field team personnel may maintain a separate dedicated notebook to document the pertinent field activities conducted directly under their supervision. For example, on large projects with multiple investigative sites and varying operating conditions, the Health and Safety Officer may elect to maintain a separate site notebook. Where several drill rigs are in operation simultaneously, each site geologist assigned to oversee a rig must maintain a site notebook.



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### **5.3 Sample Forms**

A summary of the forms illustrated in this procedure is shown as the listing of Attachments in the Table of Contents for this SOP. Forms may be altered or revised for project-specific needs contingent upon client approval. Care must be taken to ensure that all essential information can be documented. Guidelines for completing these forms can be found in the related sampling SOP.

#### **5.3.1 Sample Collection, Labeling, Shipment and Request for Analysis**

##### **5.3.1.1 Sample Log Sheet**

Sample Log Sheets are used to record specified types of data while sampling. Attachments B-1 to B-4 are examples of Sample Log Sheets. The data recorded on these sheets are useful in describing the waste source and sample as well as pointing out any problems encountered during sampling. A log sheet must be completed for each sample obtained, including field quality control (QC) samples.

##### **5.3.1.2 Sample Label**

A typical sample label is illustrated in Attachment B-5. Adhesive labels must be completed and applied to every sample container. Sample labels can usually be obtained from the appropriate Program source or are supplied from the laboratory subcontractor.

##### **5.3.1.3 Chain-of-Custody Record Form**

The Chain-of-Custody (COC) Record is a multi-part form that is initiated as samples are acquired and accompanies a sample (or group of samples) as they are transferred from person to person. This form must be used for any samples collected for chemical or geotechnical analysis whether the analyses are performed on site or off site. One part of the completed COC form is retained by the field crew while the other two or three portions are sent to the laboratory. The original (top, signed copy) and extra carbonless copies of the COC form shall be placed inside a large Ziploc-type bag and taped inside the lid of the shipping cooler. If multiple coolers are sent but are included on one COC form, the COC form should be sent with the first cooler. The COC form should then state how many coolers are included with that shipment. An example of a Chain-of-Custody Record form is provided as Attachment B-6. A supply of these forms are purchased and stocked by the field department of the various Brown & Root Environmental offices. Alternately, COC forms supplied by the laboratory may be used. Once the samples are received at the laboratory, the sample cooler and contents are checked and any problems are noted on the enclosed COC form (any discrepancies between the sample labels and COC form and any other problems that are noted are resolved through communication between the laboratory point-of-contact and the Brown & Root Environmental Project Manager). The COC form is signed and one of the remaining two parts are retained by the laboratory while the last part becomes part of the samples' corresponding analytical data package. Internal laboratory chain-of-custody procedures are documented in the Laboratory Quality Assurance Plan (LQAP).

##### **5.3.1.4 Chain-of-Custody Seal**

Attachment B-7 is an example of a custody seal. The Custody seal is also an adhesive-backed label. It is part of a chain-of-custody process and is used to prevent tampering with samples after they have been collected in the field and sealed in coolers for transit to the laboratory. The COC seals are signed and dated by the samplers and affixed across the opening edges of each cooler containing environmental samples. COC seals may be available from the laboratory; these seals may also be purchased from a supplier.



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### **5.3.2 Geohydrological and Geotechnical Forms**

#### **5.3.2.1 Groundwater Level Measurement Sheet**

A groundwater level measurement sheet, shown in Attachment C-1 must be filled out for each round of water level measurements made at a site.

#### **5.3.2.2 Data Sheet for Pumping Test**

During the performance of a pumping test (or an in-situ hydraulic conductivity test), a large amount of data must be recorded, often within a short time period. The pumping test data sheet (Attachment C-2) facilitates this task by standardizing the data collection format, and allowing the time interval for collection to be laid out in advance.

#### **5.3.2.3 Packer Test Report Form**

A packer test report form shown in Attachment C-3 must be completed for each well upon which a packer test is conducted following well installation.

#### **5.3.2.4 Summary Log of Boring**

During the progress of each boring, a log of the materials encountered, operation and driving of casing, and location of samples must be kept. The Summary Log of Boring (Attachment C-4) is used for this purpose and must be completed for each soil boring performed. In addition, if volatile organics are monitored on cores, samples or cuttings from the borehole (using HNU or OVA detectors), these results must be entered on the boring log (under the "Remarks" column) at the appropriate depth. The "Remarks" column can also be used to subsequently enter the laboratory sample number and the concentration of a few key analytical results. This feature allows direct comparison of contaminant concentrations with soil characteristics.

#### **5.3.2.5 Monitoring Well Construction Details Form**

A Monitoring Well Construction Details Form must be completed for every monitoring well piezometer or temporary well point installed. This form contains specific information on length and type of well riser pipe and screen, backfill, filter pack, annular seal and grout characteristics, and surface seal characteristics. This information is important in evaluating the performance of the monitoring well, particularly in areas where water levels show temporal variation, or where there are multiple (immiscible) phases of contaminants. Depending on the type of monitoring well (in overburden or bedrock), different forms are used (see Attachments C-5 through C-9). Similar forms are used for flush-mount well completions. The Monitoring Well Construction Details Form is not a controlled document.

#### **5.3.2.6 Test Pit Log**

When a test pit or trench is constructed for investigative or sampling purposes, a Test Pit Log (Attachment C-10) must be filled out by the responsible field geologist or sampling technician.

### **5.3.3 Equipment Calibration and Maintenance Form**

The calibration or standardization of monitoring, measuring or test equipment is necessary to assure the proper operation and response of the equipment, to document the accuracy, precision or sensitivity of the measurement, and determine if correction should be applied to the readings. Some items of



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equipment require frequent calibration, others infrequent. Some are calibrated by the manufacturer, others by the user.

Each instrument requiring calibration has its own Equipment Calibration Log (Attachment D) which documents that the manufacturer's instructions were followed for calibration of the equipment, including frequency and type of standard or calibration device. An Equipment Calibration Log must be maintained for each electronic measuring device used in the field; entries must be made for each day the equipment is used.

#### **5.4 Field Reports**

The primary means of recording onsite activities is the site logbook. Other field notebooks may also be maintained. These logbooks and notebooks (and supporting forms) contain detailed information required for data interpretation or documentation, but are not easily useful for tracking and reporting of progress. Furthermore, the field logbook/notebooks remain onsite for extended periods of time and are thus not accessible for timely review by project management.

##### **5.4.1 Weekly Status Reports**

To facilitate timely review by project management, Xeroxed copies of logbook/notebook entries may be made for internal use. To provide timely oversight of onsite contractors, Daily Activities Reports are completed and submitted as described below.

It should be noted that in addition to the summaries described herein, other summary reports may also be contractually required.

##### **5.4.2 Daily Activities Report**

###### **5.4.2.1 Description**

The Daily Activities Report (DAR) documents the activities and progress for each day's field work. This report must be filled out on a daily basis whenever there are drilling, test pitting, well construction, or other related activities occurring which involve subcontractor personnel. These sheets summarize the work performed and form the basis of payment to subcontractors (Attachment E is an example of a Daily Activities Report).

###### **5.4.2.2 Responsibilities**

It is the responsibility of the rig geologist to complete the DAR and obtain the driller's signature acknowledging that the times and quantities of material entered are correct.

###### **5.4.2.3 Submittal and Approval**

At the end of the shift, the rig geologist must submit the Daily Activities Report to the Field Operations Leader (FOL) for review and filing. The Daily Activities Report is not a formal report and thus requires no further approval. The DAR reports are retained by the FOL for use in preparing the site logbook and in preparing weekly status reports for submission to the Project Manager.



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## 6.0 ATTACHMENTS

Attachment A	TYPICAL SITE LOGBOOK ENTRY
Attachment B-1	EXAMPLE GROUNDWATER SAMPLE LOG SHEET
Attachment B-2	EXAMPLE SURFACE WATER SAMPLE LOG SHEET
Attachment B-3	EXAMPLE SOIL/SEDIMENT SAMPLE LOG SHEET
Attachment B-4	CONTAINER SAMPLE LOG SHEET FORM
Attachment B-5	SAMPLE LABEL
Attachment B-6	CHAIN-OF-CUSTODY RECORD FORM
Attachment B-7	CHAIN-OF-CUSTODY SEAL
Attachment C-1	EXAMPLE GROUNDWATER LEVEL MEASUREMENT SHEET
Attachment C-2	EXAMPLE PUMPING TEST DATA SHEET
Attachment C-3	PACKER TEST REPORT FORM
Attachment C-4	EXAMPLE BORING LOG
Attachment C-5	EXAMPLE OVERBURDEN MONITORING WELL SHEET
Attachment C-5A	EXAMPLE OVERBURDEN MONITORING WELL SHEET (FLUSHMOUNT)
Attachment C-6	EXAMPLE CONFINING LAYER MONITORING WELL SHEET
Attachment C-7	EXAMPLE BEDROCK MONITORING WELL SHEET - OPEN HOLE WELL
Attachment C-8	EXAMPLE BEDROCK MONITORING WELL SHEET - WELL INSTALLED IN BEDROCK
Attachment C-8A	EXAMPLE BEDROCK MONITORING WELL SHEET - WELL INSTALLED IN BEDROCK (FLUSHMOUNT)
Attachment C-9	EXAMPLE TEST PIT LOG
Attachment D	EXAMPLE EQUIPMENT CALIBRATION LOG
Attachment E	EXAMPLE DAILY ACTIVITIES RECORD
Attachment F	FIELD TRIP SUMMARY REPORT



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**ATTACHMENT A  
TYPICAL SITE LOGBOOK ENTRY**

START TIME: \_\_\_\_\_ DATE: \_\_\_\_\_

SITE LEADER: \_\_\_\_\_

PERSONNEL: \_\_\_\_\_

**BROWN & ROOT ENV.**

**DRILLER**

**EPA**

_____	_____	_____
_____	_____	_____
_____	_____	_____

WEATHER: Clear, 68°F, 2-5 mph wind from SE

**ACTIVITIES:**

1. Steam jenney and fire hoses were set up.
2. Drilling activities at well \_\_\_\_\_ resumes. Rig geologist was \_\_\_\_\_. See Geologist's Notebook, No. 1, page 29-30, for details of drilling activity. Sample No. 123-21-S4 collected; see sample logbook, page 42. Drilling activities completed at 11:50 and a 4-inch stainless steel well installed. See Geologist's Notebook, No. 1, page 31, and well construction details for well \_\_\_\_\_.
3. Drilling rig No. 2 steam-cleaned at decontamination pit. Then set up at location of well \_\_\_\_\_.
4. Well \_\_\_\_\_ drilled. Rig geologist was \_\_\_\_\_. See Geologist's Notebook, No. 2, page \_\_\_\_\_ for details of drilling activities. Sample numbers 123-22-S1, 123-22-S2, and 123-22-S3 collected; see sample logbook, pages 43, 44, and 45.
5. Well \_\_\_\_\_ was developed. Seven 55-gallon drums were filled in the flushing stage. The well was then pumped using the pitcher pump for 1 hour. At the end of the hour, water pumped from well was "sand free."
6. EPA remedial project manger arrives on site at 14:25 hours.
7. Large dump truck arrives at 14:45 and is steam-cleaned. Backhoe and dump truck set up over test pit \_\_\_\_\_.
8. Test pit \_\_\_\_\_ dug with cuttings placed in dump truck. Rig geologist was \_\_\_\_\_. See Geologist's Notebook, No. 1, page 32, for details of test pit activities. Test pit subsequently filled. No samples taken for chemical analysis. Due to shallow groundwater table, filling in of test pit \_\_\_\_\_ resulted in a very soft and wet area. A mound was developed and the area roped off.
9. Express carrier picked up samples (see Sample Logbook, pages 42 through 45) at 17:50 hours. Site activities terminated at 18:22 hours. All personnel off site, gate locked.

\_\_\_\_\_  
Field Operations Leader







**ATTACHMENT B-2**  
**EXAMPLE SURFACE WATER SAMPLING LOG SHEET**

[illegible]

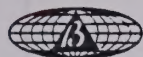






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**ATTACHMENT B-4  
CONTAINER SAMPLE LOG SHEET FORM**



Brown & Root Environmental

Page \_\_\_\_ of \_\_\_\_

☐ Container Data

Case #: \_\_\_\_\_

By: \_\_\_\_\_

Project Site Name: \_\_\_\_\_ Project Site No. \_\_\_\_\_

Brown & Root Env. Source No. \_\_\_\_\_ Source Location: \_\_\_\_\_


Container Source		Container Description			
<input type="checkbox"/> Drum <input type="checkbox"/> Bung Top <input type="checkbox"/> Lever Lock <input type="checkbox"/> Bolted Ring <input type="checkbox"/> Other _____  <input type="checkbox"/> Bag/Sack <input type="checkbox"/> Tank <input type="checkbox"/> Other _____		Color: _____ Condition: _____ Markings: _____ Vol. of Contents: _____ Other: _____			
Disposition of Sample		Sample Description			
<input type="checkbox"/> Container Sampled <input type="checkbox"/> Container opened but not sampled. Reason: _____  <input type="checkbox"/> Container not opened. Reason: _____		Phase Color Viscosity % of Total Volume Other	Layer 1 <input type="checkbox"/> Sol. <input type="checkbox"/> Liq. <input type="checkbox"/> L <input type="checkbox"/> M <input type="checkbox"/> H	Layer 2 <input type="checkbox"/> Sol. <input type="checkbox"/> Liq. <input type="checkbox"/> L <input type="checkbox"/> M <input type="checkbox"/> H	Layer 3 <input type="checkbox"/> Sol. <input type="checkbox"/> Liq. <input type="checkbox"/> L <input type="checkbox"/> M <input type="checkbox"/> H
Monitor Reading:		Type of Sample			
Sample Method:		<input type="checkbox"/> Low Concentration <input type="checkbox"/> High Concentration			
Sample Date & Time:		<input type="checkbox"/> Grab <input type="checkbox"/> Composite <input type="checkbox"/> Grab-composite			
Sampled by:		Sample Identification	Organic	Inorganic	
Signature(s):					
		Date Shipped			
Analysis:		Time Shipped			
		Lab			
		Volume			



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### ATTACHMENT B-5

### SAMPLE LABEL

 Brown & Root Environmental		PROJECT: _____	
STATION LOCATION: _____			
DATE: ____/____/____		TIME: _____ hrs.	
MEDIA:	WATER <input type="checkbox"/>	SOIL <input type="checkbox"/>	SEDIMENT <input type="checkbox"/>
CONCENTRATION:	LOW <input type="checkbox"/>	MEDIUM <input type="checkbox"/>	HIGH <input type="checkbox"/>
TYPE:	GRAB <input type="checkbox"/>	COMPOSITE <input type="checkbox"/>	
ANALYSIS		PRESERVATION	
VOA <input type="checkbox"/>	BNAs <input type="checkbox"/>	Cool to 4°C	<input type="checkbox"/>
PCBs <input type="checkbox"/>	PESTICIDES <input type="checkbox"/>	HNO <sub>3</sub> to pH < 2	<input type="checkbox"/>
METALS: TOTAL <input type="checkbox"/>	DISSOLVED <input type="checkbox"/>	NaOH to pH > 12	<input type="checkbox"/>
CYANIDE <input type="checkbox"/>			<input type="checkbox"/>
_____ <input type="checkbox"/>			
Sampled by: _____			
Remarks: _____			



**CHAIN-OF-CUSTODY RECORD FORM**  
(Original is 8.5 x 11")

Brown & Root Environmental



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**ATTACHMENT B-7**  
**CHAIN-OF-CUSTODY SEAL**

<b>Signature</b> <hr/>		<b>CUSTODY SEAL</b>
<b>Date</b> <hr/>		<hr/> <b>Date</b>
<b>CUSTODY SEAL</b>		<hr/> <b>Signature</b>













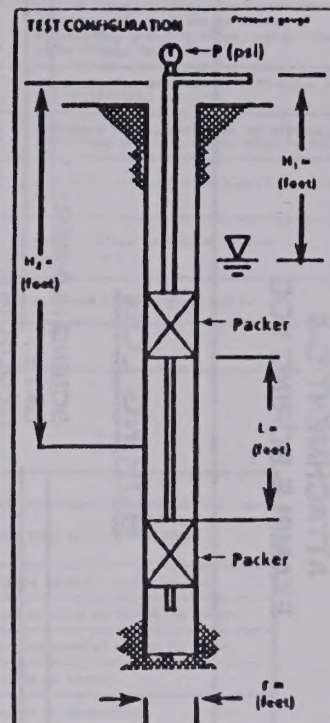
PROJECT: \_\_\_\_\_ PROJECT NO.: \_\_\_\_\_ TEST NO.: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_  
 BORING NO.: \_\_\_\_\_ CASING DEPTH: \_\_\_\_\_ CONTRACTOR: \_\_\_\_\_ STATIC WATER LEVEL \_\_\_\_\_  
 TEST INTERVAL: \_\_\_\_\_ BY: \_\_\_\_\_ CHECKED: \_\_\_\_\_ PACKER PRESSURE \_\_\_\_\_

[illegible]

CP = (1/(2 + L)) ln( L/r) (70,315.5)  
7.48 Gallons = 1 Ft<sup>3</sup>  
1 psi = 2.31 ft head  
Remarks

- $H_1$  is used when the test length is below the water table.  
 $H_2$  is used when the test length is above the water table.

Remarks



Length of Test Section in feet, <i>L</i>	<i>C<sub>p</sub></i> Draining Oil 50:50			
	<i>F<sub>1</sub></i> (15°)	<i>F<sub>2</sub></i> (1.075°)	<i>F<sub>3</sub></i> (1.317°)	<i>F<sub>4</sub></i> (1°)
1	21.000	20.500	25.000	23.500
2	19.000	18.500	18.000	15.000
5	9.000	9.500	0.000	0.000
8	6.000	5.500	6.000	5.000
10	5.700	5.400	5.000	4.900
15	0.100	3.900	3.700	3.600
20	3.200	3.500	3.000	2.900







**LEGEND**  
**SOIL TERMS**

**UNIFIED SOIL CLASSIFICATION (USCS)**

UNIFIED SOIL CLASSIFICATION (USCS)										
COARSE-GRAINED SOILS More Than Half of Material is LARGER Than No. 200 Sieve Size					FINE-GRAINED SOILS More Than Half of Material is SMALLER Than No. 200 Sieve Size					
FIELD IDENTIFICATION PROCEDURES (Excluding Particles Larger Than 3 Inches and Basing Fractions on Estimated Weights)			GROUP SYMBOL	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES (Excluding Particles Larger Than 3 Inches and Basing Fractions on Estimated Weights)				GROUP SYMBOL	TYPICAL NAMES
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size					
						DAY STRENGTH (Crushing Characteristics)	DILATANCY (Reaction to Shaking)	TOUGHNESS (Consistency Near Plastic Limit)		
GRAVELS 50X(+) > 1/4"	CLEAN GRAVELS (Low % Fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes.	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	SILTS AND CLAYS Liquid Limit < 50	None to Slight	Quick to Slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.
		Predominantly one size or a range of sizes with some intermediate sizes missing.	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.		Medium to High	None to Very Slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
	GRAVELS W/FINES (High % Fines)	Non-plastic fines (for identification procedures, see ML)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures.		Slight to Medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity.
		Plastic fines (for identification procedures, see CL)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.	SILTS AND CLAYS Liquid Limit > 50	Slight to Medium	Slow to None	Slight to Medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
SANDS 50X(+) < 1/4"	CLEAN SANDS (Low % Fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes.	SW	Well graded sand, gravelly sands, little or no fines.		High to Very High	None	High	CH	Inorganic clays of high plasticity, fat clays.
		Predominantly one size or a range of sizes with some intermediate sizes missing.	SP	Poorly graded sands, gravelly sands, little or no fines.		Medium to High	None to Very Slow	Slight to Medium	OH	Organic clays of medium to high plasticity.
	SANDS W/FINES (High % Fines)	Non-plastic fines (for identification procedures, see MCL)	SM	Silty sands, poorly graded sand-silt mixtures.	HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel and frequently by fibrous texture.			PT	Peat and other organic soils
		Plastic fines (for identification procedures, see CL)	SC	Clayey sands, poorly graded sand-clay mixtures.						

Boundary classifications: Soils possessing characteristics of two groups are designated by combining group symbols. For example, GW-GC, well graded gravel-sand mixture with clay binder. All sieve sizes on this chart are U.S. Standard.

DENSITY OF GRANULAR SOILS	
DESIGNATION	STANDARD PENETRATION RESISTANCE-BLOWS/FOOT
Very Loose	0-4
Loose	5-10
Medium Loose	11-30
Dense	31-50
Very Dense	Over 50

CONSISTENCY OF COHESIVE SOILS			
CONSISTENCY	UNC COMPRESSIVE STRENGTH (TONS/SQ. FT.)	STANDARD PENETRATION RESISTANCE-BLOWS/FOOT	FIELD IDENTIFICATION METHODS
Very Soft	Less than 0.25	0 to 2	Easily penetrated several inches by fist
Soft	0.25 to 0.50	2 to 4	Easily penetrated several inches by thumb.
Medium Stiff	0.50 to 1.0	4 to 8	Can be penetrated several inches by thumb.
Stiff	1.0 to 2.0	8 to 15	Readily indented by thumb.
Very Stiff	2.0 to 4.0	15 to 30	Readily indented by thumbnail.
Hard	More than 4.0	Over 30	Indented with difficulty by thumbnail.

**ROCK TERMS**

ROCK HARDNESS (FROM CORE SAMPLES)			ROCK BROKENESS		
Descriptive Terms	Screwdriver or Knife Effects	Hammer Effects	Descriptive Terms	Abbreviation	Spacing
Soft	Easily gouged	Crushes when pressed with hammer	Very Broken	(V. Br.)	0-2"
Medium Soft	Can be gouged	Breaks (one blow); crumbly edges	Broken	(Br.)	2"-1'
Medium Hard	Can be scratched	Breaks (one blow); sharp edges	Blocky	(Bl.)	1'-3"
Hard	Cannot be scratched	Breaks conchoidally (several blows); sharp edges	Massive	(M.)	3'-10'

**LEGEND:**

**SOIL SAMPLES - TYPES**  
 S-2" Split-Barrel Sample  
 S1-3" O.D. Undisturbed Sample  
 O - Other Samples, Specify in Remarks

**ROCK SAMPLES - TYPES**  
 X-MX (Conventional) Core (-2-1/8" O.D.)  
 Q-MQ (Wireline) Core (-1-7/8" O.D.)  
 Z - Other Core Sizes, Specify in Remarks


**WATER LEVELS**

12/10      12.6'      Initial Level w/Date & Depth  
 12/10      12.6'      Stabilized Level w/Date & Depth

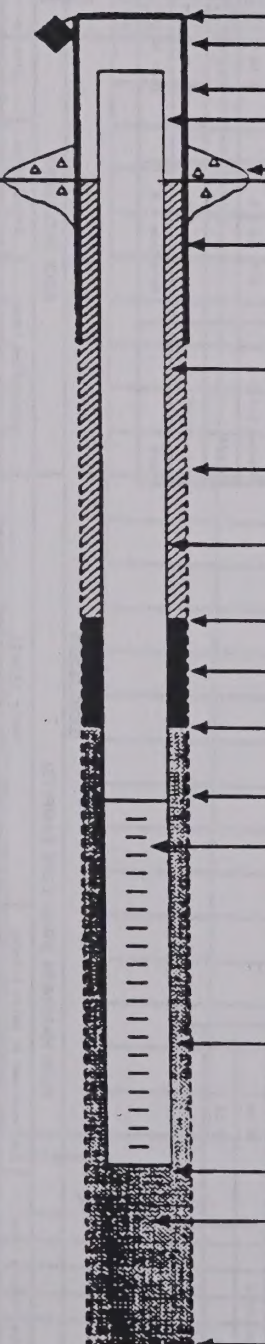


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**ATTACHMENT C-5  
EXAMPLE OVERBURDEN MONITORING WELL SHEET**

		BORING NO.: _____
<b>OVERBURDEN MONITORING WELL SHEET</b>		
PROJECT _____	LOCATION _____	DRILLER _____
PROJECT NO. _____	BORING _____	DRILLING _____
ELEVATION _____	DATE _____	METHOD _____
FIELD GEOLOGIST _____		DEVELOPMENT _____
		METHOD _____


	ELEVATION OF TOP OF SURFACE CASING : _____
	ELEVATION OF TOP OF RISER PIPE : _____
	STICK - UP TOP OF SURFACE CASING : _____
	STICK - UP RISER PIPE : _____
	TYPE OF SURFACE SEAL: _____
	I.D. OF SURFACE CASING: _____
	TYPE OF SURFACE CASING: _____
	RISER PIPE I.D. _____
	TYPE OF RISER PIPE: _____
	BOREHOLE DIAMETER: _____
	TYPE OF BACKFILL: _____
	ELEVATION / DEPTH TOP OF SEAL: _____ / _____
	TYPE OF SEAL: _____
	DEPTH TOP OF SAND PACK: _____
	ELEVATION / DEPTH TOP OF SCREEN: _____ / _____
TYPE OF SCREEN: _____	
SLOT SIZE x LENGTH: _____	
I.D. OF SCREEN: _____	
TYPE OF SAND PACK: _____	
ELEVATION / DEPTH BOTTOM OF SCREEN: _____ / _____	
ELEVATION / DEPTH BOTTOM OF SAND PACK: _____ / _____	
TYPE OF BACKFILL BELOW OBSERVATION WELL: _____	
ELEVATION / DEPTH OF HOLE: _____ / _____	



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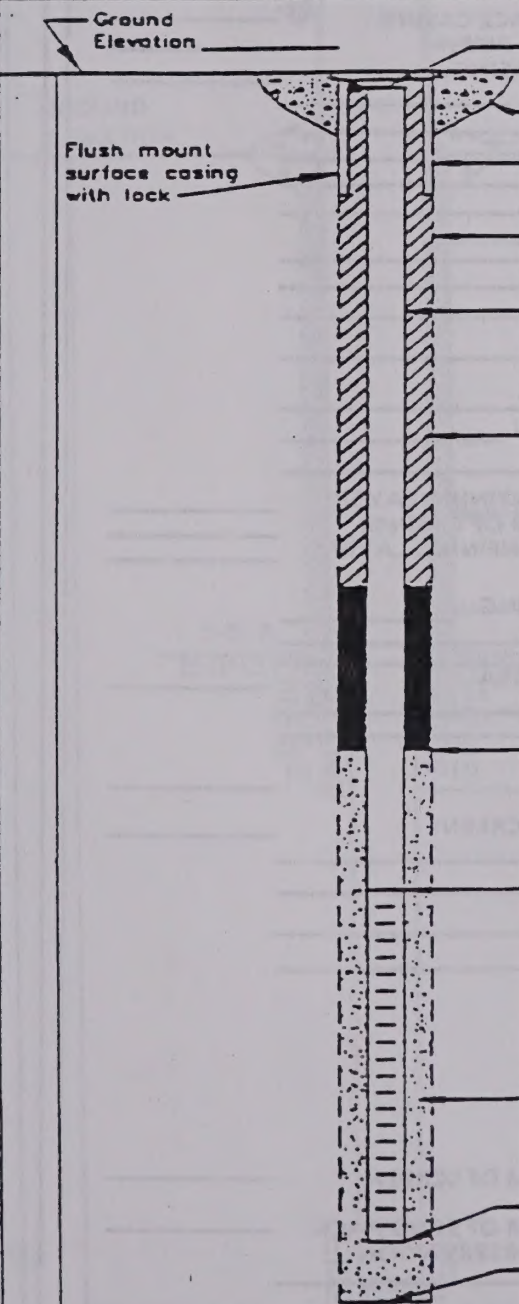
**ATTACHMENT C-5A  
EXAMPLE OVERBURDEN MONITORING WELL SHEET (FLUSHMOUNT)**

BORING NO.: \_\_\_\_\_



## MONITORING WELL SHEET

PROJECT _____ PROJECT NO. _____ ELEVATION _____ FIELD GEOLOGIST _____	LOCATION _____ BORING _____ DATE _____	DRILLER _____ DRILLING METHOD _____ DEVELOPMENT METHOD _____
--	--	--



ELEVATION TOP OF RISER: \_\_\_\_\_

TYPE OF SURFACE SEAL: \_\_\_\_\_

TYPE OF PROTECTIVE CASING: \_\_\_\_\_

I.D. OF PROTECTIVE CASING: \_\_\_\_\_

DIAMETER OF HOLE: \_\_\_\_\_

TYPE OF RISER PIPE: \_\_\_\_\_

RISER PIPE I.D.: \_\_\_\_\_

TYPE OF BACKFILL/SEAL: \_\_\_\_\_

DEPTH/ELEVATION TOP OF SAND: \_\_\_\_\_

DEPTH/ELEVATION TOP OF SCREEN: \_\_\_\_\_

TYPE OF SCREEN: \_\_\_\_\_

SLOT SIZE x LENGTH: \_\_\_\_\_

TYPE OF SAND PACK: \_\_\_\_\_

DIAMETER OF HOLE IN BEDROCK: \_\_\_\_\_

DEPTH/ELEVATION BOTTOM OF SCREEN: \_\_\_\_\_

DEPTH/ELEVATION BOTTOM OF SAND: \_\_\_\_\_

DEPTH/ELEVATION BOTTOM OF HOLE: \_\_\_\_\_

BACKFILL MATERIAL BELOW SAND: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

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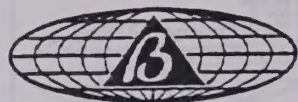
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**ATTACHMENT C-6  
EXAMPLE CONFINING LAYER MONITORING WELL SHEET**

BORING NO.: \_\_\_\_\_



**CONFINING LAYER  
MONITORING WELL SHEET**

PROJECT _____	LOCATION _____	DRILLER _____
PROJECT NO. _____	BORING _____	DRILLING _____
ELEVATION _____	DATE _____	METHOD _____
FIELD GEOLOGIST _____		DEVELOPMENT _____
		METHOD _____

	ELEVATION OF TOP OF SURFACE CASING : _____
	ELEVATION OF TOP OF RISER PIPE: _____
	ELEVATION TOP OF PERM. CASING: _____
	TYPE OF SURFACE SEAL: _____
	I.D. OF SURFACE CASING: _____
	TYPE OF SURFACE CASING: _____
	RISER PIPE I.D. _____
	TYPE OF RISER PIPE: _____
	BOREHOLE DIAMETER: _____
	PERM. CASING I.D. _____
	TYPE OF CASING & BACKFILL: _____
	ELEVATION / DEPTH TOP CONFINING LAYER: _____
	ELEVATION / DEPTH BOTTOM OF CASING: _____
	ELEVATION / DEPTH BOT. CONFINING LAYER: _____
	BOREHOLE DIA. BELOW CASING: _____
TYPE OF BACKFILL: _____	
ELEVATION / DEPTH TOP OF SEAL: _____	
TYPE OF SEAL: _____	
DEPTH TOP OF SAND PACK: _____	
ELEVATION/DEPTH TOP OF SCREEN: _____	
TYPE OF SCREEN: _____	
TYPE OF SAND PACK: _____	
ELEVATION / DEPTH BOTTOM OF SCREEN: _____	
ELEVATION / DEPTH BOTTOM OF SAND PACK: _____	
TYPE OF BACKFILL BELOW OBSERVATION WELL: _____	
ELEVATION / DEPTH OF HOLE: _____	



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**ATTACHMENT C-7**  
**EXAMPLE BEDROCK MONITORING WELL SHEET - OPEN HOLE WELL**

BORING NO.: \_\_\_\_\_



**BEDROCK  
MONITORING WELL SHEET  
OPEN HOLE WELL**


PROJECT _____	LOCATION _____	DRILLER _____
PROJECT NO. _____	BORING _____	DRILLING _____
ELEVATION _____	DATE _____	METHOD _____
FIELD GEOLOGIST _____		DEVELOPMENT _____
		METHOD _____

	ELEVATION OF TOP OF CASING: _____
	STICK UP OF CASING ABOVE GROUND SURFACE: _____
	TYPE OF SURFACE SEAL: _____
	I.D. OF CASING: _____
	TYPE OF CASING: _____
	TEMP. / PERM.: _____
	DIAMETER OF HOLE: _____
	TYPE OF CASING SEAL: _____
	DEPTH TO TOP OF ROCK: _____
	DEPTH TO BOTTOM CASING: _____
DIAMETER OF HOLE IN BEDROCK: _____	
DESCRIBE IF CORE / REAMED WITH BIT: _____ _____ _____	
DESCRIBE JOINTS IN BEDROCK AND DEPTH: _____ _____ _____	
ELEVATION / DEPTH OF HOLE: _____	



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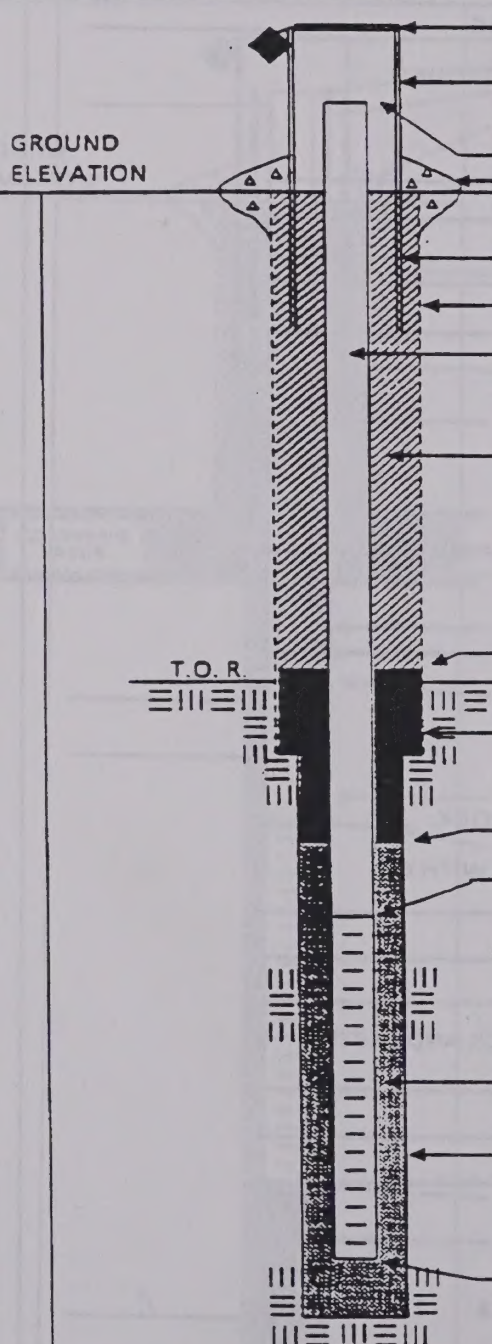
**ATTACHMENT C-8**  
**EXAMPLE BEDROCK MONITORING WELL SHEET - WELL INSTALLED IN BEDROCK**



**BEDROCK  
MONITORING WELL SHEET**  
**WELL INSTALLED IN BEDROCK**

BORING NO.: \_\_\_\_\_

PROJECT _____ PROJECT NO. _____ ELEVATION _____ FIELD GEOLOGIST _____	LOCATION _____ BORING _____ DATE _____	DRILLER _____ DRILLING _____ METHOD _____ DEVELOPMENT _____ METHOD _____
--	--	--



ELEVATION OF TOP OF SURFACE CASING: \_\_\_\_\_

STICK UP OF CASING ABOVE GROUND SURFACE: \_\_\_\_\_

ELEVATION TOP OF RISER: \_\_\_\_\_

TYPE OF SURFACE SEAL: \_\_\_\_\_

I.D. OF SURFACE CASING: \_\_\_\_\_

DIAMETER OF HOLE: \_\_\_\_\_

RISER PIPE I.D.: \_\_\_\_\_

TYPE OF RISER PIPE: \_\_\_\_\_

TYPE OF BACKFILL: \_\_\_\_\_

ELEVATION / DEPTH TOP OF SEAL: \_\_\_\_\_

ELEVATION / DEPTH TOP OF BEDROCK: \_\_\_\_\_

TYPE OF SEAL: \_\_\_\_\_

ELEVATION / DEPTH TOP OF SAND: \_\_\_\_\_

ELEVATION / DEPTH TOP OF SCREEN: \_\_\_\_\_

TYPE OF SCREEN: \_\_\_\_\_

SLOT SIZE x LENGTH: \_\_\_\_\_

I.D. SCREEN: \_\_\_\_\_

TYPE OF SAND PACK: \_\_\_\_\_

DIAMETER OF HOLE IN BEDROCK: \_\_\_\_\_

CORE / REAM: \_\_\_\_\_

ELEVATION / DEPTH BOTTOM SCREEN: \_\_\_\_\_

ELEVATION / DEPTH BOTTOM OF HOLE: \_\_\_\_\_



**ATTACHMENT C-8A  
EXAMPLE BEDROCK MONITORING WELL SHEET  
WELL INSTALLED IN BEDROCK (FLUSHMOUNT)**

BORING NO.: \_\_\_\_\_



**BEDROCK  
MONITORING WELL SHEET  
WELL INSTALLED IN BEDROCK**

PROJECT: _____	LOCATION: _____	DRILLER: _____
PROJECT NO.: _____	BORING: _____	DRILLING METHOD: _____
ELEVATION: _____	DATE: _____	DEVELOPMENT METHOD: _____
FIELD GEOLOGIST: _____		

Ground Elevation \_\_\_\_\_

Flush mount surface casing with lock

Top of Rock

Depth/Elevation Static Water Level (Approx.)

2' PVC Trap Below Screen

ELEVATION TOP OF RISER: \_\_\_\_\_

TYPE OF SURFACE SEAL: \_\_\_\_\_

TYPE OF PROTECTIVE CASING: \_\_\_\_\_

I.D. OF PROTECTIVE CASING: \_\_\_\_\_

DIAMETER OF HOLE: \_\_\_\_\_

TYPE OF RISER PIPE: \_\_\_\_\_

RISER PIPE I.D.: \_\_\_\_\_

TYPE OF BACKFILL/SEAL: \_\_\_\_\_

DEPTH/ELEVATION TOP OF BEDROCK: \_\_\_\_\_

DEPTH/ELEVATION TOP OF SAND: \_\_\_\_\_

DEPTH/ELEVATION TOP OF SCREEN: \_\_\_\_\_

TYPE OF SCREEN: \_\_\_\_\_

SLOT SIZE x LENGTH: \_\_\_\_\_

TYPE OF SAND PACK: \_\_\_\_\_

DIAMETER OF HOLE IN BEDROCK: \_\_\_\_\_

DEPTH/ELEVATION BOTTOM OF SCREEN: \_\_\_\_\_

DEPTH/ELEVATION BOTTOM OF SAND: \_\_\_\_\_

DEPTH/ELEVATION BOTTOM OF HOLE: \_\_\_\_\_

BACKFILL MATERIAL BELOW SAND: \_\_\_\_\_

NOTES: (1) 7/1/96 (2) 1/1/96 (3) 1/1/96

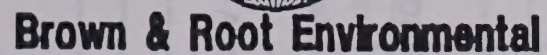






## ATTACHMENT D

### EXAMPLE EQUIPMENT CALIBRATION LOG



## INSTRUMENT NAME / MODEL : \_\_\_\_\_

**JOB NAME :** \_\_\_\_\_

MANUFACTURER : \_\_\_\_\_

**JOB NUMBER :** \_\_\_\_\_

019611/P







Subject <b>FIELD DOCUMENTATION</b>	Number <b>SA-6.3</b>	Page <b>31 of 32</b>
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**ATTACHMENT F  
FIELD TRIP SUMMARY REPORT  
PAGE 1 OF 2**

**SUNDAY**

Date: \_\_\_\_\_ Personnel: \_\_\_\_\_  
Weather: \_\_\_\_\_ Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**MONDAY**

Date: \_\_\_\_\_ Personnel: \_\_\_\_\_  
Weather: \_\_\_\_\_ Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**TUESDAY**

Date: \_\_\_\_\_ Personnel: \_\_\_\_\_  
Weather: \_\_\_\_\_ Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**WEDNESDAY**

Date: \_\_\_\_\_ Personnel: \_\_\_\_\_  
Weather: \_\_\_\_\_ Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



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	Revision <b>0</b>	Effective Date <b>03/01/96</b>

**ATTACHMENT F  
PAGE 2 OF 2  
FIELD TRIP SUMMARY REPORT**

**THURSDAY**

Date: \_\_\_\_\_  
Weather: \_\_\_\_\_

Personnel: \_\_\_\_\_  
Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**FRIDAY**

Date: \_\_\_\_\_  
Weather: \_\_\_\_\_

Personnel: \_\_\_\_\_  
Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

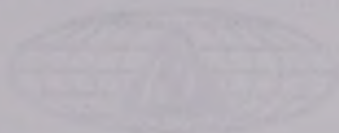
**SATURDAY**

Date: \_\_\_\_\_  
Weather: \_\_\_\_\_

Personnel: \_\_\_\_\_  
Onsite: \_\_\_\_\_

Site Activities: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_





# STANDARD OPERATING PROCEDURES

BROWN & ROOT ENVIRONMENTAL

Number	SA7.1	Page	1 of 9
Effective Date	03/21/97	Revised	1
Application	SAB Environmental NE		
Prepared	Earth Technical Department		
Reviewed	D. D. Brown		

Topic: DECONTAMINATION OF FIELD EQUIPMENT  
AND WASTE HANDLING

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		REVISION	0	PREPARED BY	2201-10

ATTACHMENT 8  
PAGE 2 OF 2  
FIELD TRIP SUMMARY REPORT

THURSDAY

DATE \_\_\_\_\_ TIME \_\_\_\_\_  
WEATHER \_\_\_\_\_ CHART \_\_\_\_\_

SEA AREA \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

FRIDAY

DATE \_\_\_\_\_ TIME \_\_\_\_\_  
WEATHER \_\_\_\_\_ CHART \_\_\_\_\_

SEA AREA \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

SATURDAY

DATE \_\_\_\_\_ TIME \_\_\_\_\_  
WEATHER \_\_\_\_\_ CHART \_\_\_\_\_

SEA AREA \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_





BROWN & ROOT ENVIRONMENTAL

# STANDARD OPERATING PROCEDURES

Number  
SA-7.1

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01/21/97

Revision  
1

Applicability  
B&R Environmental, NE

Prepared  
Earth Sciences Department

Subject  
DECONTAMINATION OF FIELD EQUIPMENT  
AND WASTE HANDLING

Approved  
D. Senovich

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## 1.0 PURPOSE

The purpose of this procedure is to provide guidelines regarding the appropriate procedures to be followed when decontaminating drilling equipment, monitoring well materials, chemical sampling equipment and field analytical equipment.

## 2.0 SCOPE

This procedure addresses drilling equipment and monitoring well materials decontamination, as well as chemical sampling and field analytical equipment decontamination. This procedure also provides general reference information on the control of contaminated materials.

## 3.0 GLOSSARY

**Acid** - For decontamination of equipment when sampling for trace levels of inorganics, a 10% solution of nitric acid in deionized water should be used. Due to the leaching ability of nitric acid, it should not be used on stainless steel.

**Alconox/Liquinox** - A brand of phosphate-free laboratory-grade detergent.

**Deionized Water** - Deionized (analyte free) water is tap water that has been treated by passing through a standard deionizing resin column. Deionized water should contain no detectable heavy metals or other inorganic compounds at or above the analytical detection limits for the project.

**Potable Water** - Tap water used from any municipal water treatment system. Use of an untreated potable water supply is not an acceptable substitute for tap water.

**Solvent** - The solvent of choice is pesticide-grade Isopropanol. Use of other solvents (methanol, acetone, pesticide-grade hexane, or petroleum ether) may be required for particular projects or for a particular purpose (e.g. for the removal of concentrated waste) and must be justified in the project planning documents. As an example, it may be necessary to use hexane when analyzing for trace levels of pesticides, PCBs, or fuels. In addition, because many of these solvents are not miscible in water, the equipment should be air dried prior to use. Solvents should not be used on PVC equipment or well construction materials.

## 4.0 RESPONSIBILITIES

**Project Manager** - Responsible for ensuring that all field activities are conducted in accordance with approved project plan(s) requirements.

**Field Operations Leader (FOL)** - Responsible for the onsite verification that all field activities are performed in compliance with approved Standards Operating Procedures or as otherwise dictated by the approved project plan(s).

## 5.0 PROCEDURES

To ensure that analytical chemical results reflect actual contaminant concentrations present at sampling locations, the various drilling equipment and chemical sampling and analytical equipment used to acquire the environment sample must be properly decontaminated. Decontamination minimizes the potential for cross-contamination between sampling locations, and the transfer of contamination off site.



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## 5.1 Drilling Equipment

Prior to the initiation of a drilling program, all drilling equipment involved in field sampling activities shall be decontaminated by steam cleaning at a predetermined area. The steam cleaning procedure shall be performed using a high-pressure spray of heated potable water producing a pressurized stream of steam. This steam shall be sprayed directly onto all surfaces of the various equipment which might contact environmental samples. The decontamination procedure shall be performed until all equipment is free of all visible potential contamination (dirt, grease, oil, noticeable odors, etc.) In addition, this decontamination procedure shall be performed at the completion of each sampling and/or drilling location, including soil borings, installation of monitoring wells, test pits, etc. Such equipment shall include drilling rigs, backhoes, downhole tools, augers, well casings, and screens. Where the drilling rig is set to perform multiple borings at a single area of concern, the steam-cleaning of the drilling rig itself may be waived with proper approval. Downhole equipment, however, must always be steam-cleaned between borings. Where PVC well casings are to be installed, decontamination is not required if the manufacturer provides these casings in factory-sealed, protective, plastic sleeves (so long as the protective packaging is not compromised until immediately before use).

The steam cleaning area shall be designed to contain decontamination wastes and waste waters and can be a lined excavated pit or a bermed concrete or asphalt pad. For the latter, a floor drain must be provided which is connected to a holding facility. A shallow above-ground tank may be used or a pumping system with discharge to a waste tank may be installed.

In certain cases such an elaborate decontamination pad is not possible. In such cases, a plastic lined gravel bed pad with a collection system may serve as an adequate decontamination area. Alternately, a lined sloped pad with a collection pump installed at the lower end may be permissible. The location of the steam cleaning area shall be onsite in order to minimize potential impacts at certain sites.

Guidance to be used when decontaminating drilling equipment shall include:

- As a general rule, any part of the drilling rig which extends over the borehole, shall be steam cleaned.
- All drilling rods, augers, and any other equipment which will be introduced to the hole shall be steam cleaned.
- The drilling rig, all rods and augers, and any other potentially contaminated equipment shall be decontaminated between each well location to prevent cross contamination of potential hazardous substances.

Prior to leaving at the end of each work day and/or at the completion of the drilling program, drilling rigs and transport vehicles used onsite for personnel or equipment transfer shall be steam cleaned, as practicable. A drilling rig left at the drilling location does not need to be steam cleaned until it is finished drilling at that location.

## 5.2 Sampling Equipment

### 5.2.1 Bailers and Bailing Line

The potential for cross-contamination between sampling points through the use of a common bailer or its attached line is high unless strict procedures for decontamination are followed. For this reason, it is preferable to dedicate an individual bailer and its line to each sample point, although this does not



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eliminate the need for decontamination of dedicated bailers. For non-dedicated sampling equipment, the following conditions and/or decontamination procedures must be followed.

Before the initial sampling and after each successive sampling point, the bailer must be decontaminated. The following steps are to be performed when sampling for organic contaminants. Note: contract-specific requirements may permit alternative procedures.

- Potable water rinse
- Alconox or Liquinox detergent wash
- Scrubbing of the line and bailer with a scrub brush (may be required if the sample point is heavily contaminated with heavy or extremely viscous compounds)
- Potable water rinse
- Rinse with 10 percent nitric acid solution\*
- Deionized water rinse
- Pesticide-grade isopropanol (unless otherwise required)
- Pesticide-grade hexane rinse\*\*
- Copious distilled/Deionized water rinse
- Air dry

If sampling for volatile organic compounds (VOCs) only, the nitric acid, isopropanol, and hexane rinses may be omitted. Only reagent grade or purer solvents are to be used for decontamination. When solvents are used, the bailer must be thoroughly dry before using to acquire the next sample.

In general, specially purchased pre-cleaned disposable sampling equipment is not decontaminated (nor is an equipment rinsate blank collected) so long as the supplier has provided certification of cleanliness. If decontamination is performed on several bailers at once (i.e., in batches), bailers not immediately used may be completely wrapped in aluminum foil (shiny-side toward equipment) and stored for future use. When batch decontamination is performed, one equipment rinsate is generally collected from one of the bailers belonging to the batch before it is used for sampling.

It is recommended that clean, dedicated braided nylon or polypropylene line be employed with each bailer use.

### 5.2.2 Sampling Pumps

Most sampling pumps are low volume (less than 2 gpm) pumps. These include peristaltic, diaphragm, air-lift, pitcher and bladder pumps, to name a few. If these pumps are used for sampling from more than one sampling point, they must be decontaminated prior to initial use and after each use.

The procedures to be used for decontamination of sampling pumps compare to those used for a bailer except that the 10 percent nitric acid solution is omitted. Each of the liquid fractions is to be pumped through the system. The amount of pumping is dependent upon the size of the pump and the length of the intake and discharge hoses. Certain types of pumps are unacceptable for sampling purposes. For peristaltic pumps, the tubing is replaced rather than cleaned.

---

\* Due to the leaching ability of nitric acid on stainless steel, this step is to be omitted if a stainless steel sampling device is being used and metals analysis is required with detection limits less than approximately 50 ppb.

\*\* If sampling for pesticides, PCBs, or fuels.



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An additional problem is introduced when the pump relies on absorption of water via an inlet or outlet hose. For organic sampling, this hose should be Teflon. Other types of hoses leach organics (especially phthalate esters) into the water being sampled or adsorb organics from the sampled water. For all other sampling, the hose should be Viton, polyethylene, or polyvinyl chloride (listed in order of preference). Whenever possible, dedicated hoses should be used. It is preferable that these types of pumps not be used for sampling, only for purging.

### **5.2.3 Filtering Equipment**

On occasion, the sampling plan may require acquisition of filtered groundwater samples. Field-filtering is addressed in SOP SA-6.1 and should be conducted as soon after sample acquisition as possible. To this end, three basic filtration systems are most commonly used: the in-line disposable Teflon filter, the inert gas over-pressure filtration system, and the vacuum filtration system.

For the in-line filter, decontamination is not required since the filter cartridge is disposable, however, the cartridge must be disposed of in an approved receptacle and the intake and discharge lines must still be decontaminated or replaced before each use.

For the over-pressure and the vacuum filtration systems, the portions of the apparatus which come in contact with the sample must be decontaminated as outlined in the paragraphs describing the decontamination of bailers. (Note: Varieties of both of these systems come equipped from the manufacturer with Teflon-lined surfaces for those that would come into contact with the sample. These filtration systems are preferred when decontamination procedures must be employed.)

### **5.2.4 Other Sampling Equipment**

Field tools such as trowels and mixing bowls are to be decontaminated in the same manner as described above.

## **5.3 Field Analytical Equipment**

### **5.3.1 Water Level Indicators**

Water level indicators that come into contact with groundwater must be decontaminated using the following steps:

- Rinse with potable water
- Rinse with deionized water
- Pesticide-grade isopropanol (unless otherwise directed by manufacturer)
- Rinse with deionized water

Water level indicators that do not come in contact with the groundwater but may encounter incidental contact during installation or retrieval need only undergo the first and last steps stated above.

### **5.3.2 Probes**

Probes (e.g., pH or specific-ion electrodes, geophysical probes, or thermometers) which would come in direct contact with the sample, will be decontaminated using the procedures specified above unless manufacturer's instructions indicate otherwise (e.g., dissolved oxygen probes). Probes that contact a volume of groundwater not used for laboratory analyses can be rinsed with deionized water. For probes which make no direct contact, (e.g., OVA equipment) the probe is self-cleaning when exposure to



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uncontaminated air is allowed and the housing can be wiped clean with paper-towels or cloth wetted with alcohol.

#### **5.4 Waste Handling**

For the purposes of these procedures, contaminated materials are defined as any byproducts of field activities that are suspected or known to be contaminated with hazardous substances. These byproducts include such materials as decontamination solutions, disposable equipment, drilling muds, well-development fluids, and spill-contaminated materials and Personal Protection Equipment (PPE).

The procedures for obtaining permits for investigations of sites containing hazardous substances are not clearly defined at present. In the absence of a clear directive to the contrary by the EPA and the states, it must be assumed that hazardous wastes generated during field activities will require compliance with Federal agency requirements for generation, storage, transportation, or disposal. In addition, there may be state regulations that govern the disposal action. This procedure exclusively describes the technical methods used to control contaminated materials.

The plan documents for site activities must include a description of control procedures for contaminated materials. This planning strategy must assess the type of contamination, estimate the amounts that would be produced, describe containment equipment and procedures, and delineate storage or disposal methods. As a general policy, it is wise to select investigation methods that minimize the generation of contaminated spoils. Handling and disposing of potentially hazardous materials can be dangerous and expensive. Until sample analysis is complete, it is assumed that all produced materials are suspected of contamination from hazardous chemicals and require containment.

#### **5.5 Sources of Contaminated Materials and Containment Methods**

##### **5.5.1 Decontamination Solutions**

All waste decontamination solutions and rinses must be assumed to contain the hazardous chemicals associated with the site unless there are analytical or other data to the contrary. The waste solution volumes could vary from a few gallons to several hundred gallons in cases where large equipment required cleaning.

Containerized waste rinse solutions are best stored in 55-gallon drums (or equivalent containers) that can be sealed until ultimate disposal at an approved facility. Larger equipment such as backhoes and tractors must be decontaminated in an area provided with an impermeable liner and a liquid collection system. A decontamination area for large equipment could consist of a bermed concrete pad with a floor drain leading to a buried holding tank.

##### **5.5.2 Disposable Equipment**

Disposable equipment that could become contaminated during use typically includes PPE, rubber gloves, boots, broken sample containers, and cleaning-wipes. These items are small and can easily be contained in 55-gallon drums with lids. These containers should be closed at the end of each work day and upon project completion to provide secure containment until disposed.

##### **5.5.3 Drilling Mud and Well-Development Fluids**

Drilling muds and well-development fluids are materials that may be used in groundwater monitoring well installations. Their proper use could result in the surface accumulation of contaminated liquids and muds



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that require containment. The volumes of drilling muds and well-development fluids used depend on well diameter and depth, groundwater characteristics, and geologic formations. There are no simple mathematical formulas available for accurately predicting these volumes. It is best to rely on the experience of reputable well drillers familiar with local conditions and the well installation techniques selected. These individuals should be able to estimate the sizes (or number) of containment structures required. Since guesswork is involved, it is recommended that an slight excess of the estimated amount of containers required will be available.

Drilling muds are mixed and stored in what is commonly referred to as a mud pit. This mud pit consists of a suction section from which drilling mud is withdrawn and pumped through hoses, down the drill pipe to the bit, and back up the hole to the settling section of the mud pit. In the settling section, the mud's velocity is reduced by a screen and several flow-restriction devices, thereby allowing the well cuttings to settle out of the mud/fluid.

The mud pit may be either portable above-ground tanks commonly made of steel (which is preferred) or stationary in-ground pits as depicted in Attachment A. The above-ground tanks have a major advantage over the in-ground pits because the above-ground tanks isolate the natural soils from the contaminated fluids within the drilling system. These tanks are also portable and can usually be cleaned easily.

As the well is drilled, the cuttings that accumulate in the settling section must be removed. This is best done by shoveling them into drums or other similar containers. When the drilling is complete, the contents of the above-ground tank are likewise shoveled or pumped into drums, and the tank is cleaned and made available for its next use.

If in-ground pits are used, they should not extend into the natural water table. They should also be lined with a bentonite-cement mixture followed by a layer of flexible impermeable material such as plastic sheeting. Of course, to maintain its impermeable seal, the lining material used would have to be nonreactive with the wastes. An advantage of the in-ground pits is that well cuttings do not necessarily have to be removed periodically during drilling because the pit can be made deep enough to contain them. Depending on site conditions, the in-ground pit may have to be totally excavated and refilled with uncontaminated natural soils when the drilling operation is complete.

When the above-ground tank or the in-ground pit is used, a reserve tank or pit should be located at the site as a backup system for leaks, spills, and overflows. In either case, surface drainage should be such that any excess fluid could be controlled within the immediate area of the drill site.

The containment procedure for well-development fluids is similar to that for drilling muds. The volume and weight of contaminated fluid will be determined by the method used for development. When a new well is pumped or bailed to produce clear water, substantially less volume and weight of fluid result than when backwashing or high-velocity jetting is used.

#### **5.5.4 Spill-Contaminated Materials**

A spill is always possible when containers of liquids are opened or moved. Contaminated sorbents and soils resulting from spills must be contained. Small quantities of spill-contaminated materials are usually best contained in drums, while larger quantities can be placed in lined pits or in other impermeable structures. In some cases, onsite containment may not be feasible and immediate transport to an approved disposal site will be required.



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## 5.6 Disposal of Contaminated Materials

Actual disposal techniques for contaminated materials are the same as those for any hazardous substance, that is, incineration, landfilling, treatment, and so on. The problem centers around the assignment of responsibility for disposal. The responsibility must be determined and agreed upon by all involved parties before the field work starts. If the site owner or manager was involved in activities that precipitated the investigation, it seems reasonable to encourage his acceptance of the disposal obligation. In instances where a responsible party cannot be identified, this responsibility may fall on the public agency or private organization investigating the site.

Another consideration in selecting disposal methods for contaminated materials is whether the disposal can be incorporated into subsequent site cleanup activities. For example, if construction of a suitable onsite disposal structure is expected, contaminated materials generated during the investigation should be stored at the site for disposal with other site materials. In this case, the initial containment structures should be evaluated for use as long-term storage structures. Also, other site conditions such as drainage control, security, and soil type must be considered so that proper storage is provided. If onsite storage is expected, then the containment structures should be specifically designed for that purpose.

## 6.0 REFERENCES

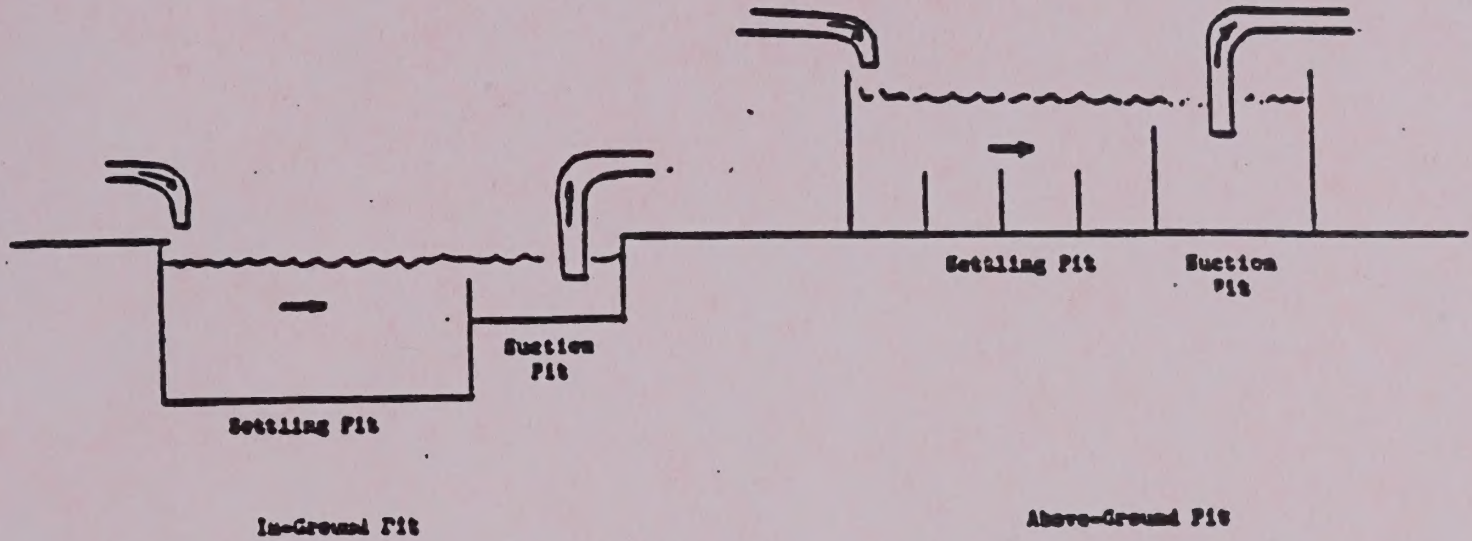
Brown & Root Environmental: Standard Operating Procedure No. 4.33, Control of Contaminated Material.



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# ATTACHMENT A

## TWO TYPES OF MUD PITS USED IN WELL DRILLING

















**APPENDIX V**  
**SELECTED ASTM METHODS**







## Standard Test Method for Particle-Size Analysis of Soils

This standard is a part of the *Standard Test Methods for Soil and Rock Properties* published by the American Society of Civil Engineers (ASCE). It is a part of the *Standard Test Methods for Soil and Rock Properties* published by the American Society of Civil Engineers (ASCE).

This standard is a part of the *Standard Test Methods for Soil and Rock Properties* published by the American Society of Civil Engineers (ASCE). It is a part of the *Standard Test Methods for Soil and Rock Properties* published by the American Society of Civil Engineers (ASCE).

### 1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes in soils. The test is applicable to soils having a maximum particle size of 75 mm (3 in.) and a minimum particle size of 0.075 mm (No. 200 sieve). The test is applicable to soils having a maximum particle size of 75 mm (3 in.) and a minimum particle size of 0.075 mm (No. 200 sieve).

1.2 This test method is applicable to soils having a maximum particle size of 75 mm (3 in.) and a minimum particle size of 0.075 mm (No. 200 sieve). The test is applicable to soils having a maximum particle size of 75 mm (3 in.) and a minimum particle size of 0.075 mm (No. 200 sieve).

1.3 This test method is applicable to soils having a maximum particle size of 75 mm (3 in.) and a minimum particle size of 0.075 mm (No. 200 sieve). The test is applicable to soils having a maximum particle size of 75 mm (3 in.) and a minimum particle size of 0.075 mm (No. 200 sieve).

### 2. Referenced Documents

#### 2.1 Standards and Specifications

2.1.1 American Society of Civil Engineers (ASCE) Standard Test Method for Soil and Rock Properties (ASCE 2013).

2.1.2 American Society of Civil Engineers (ASCE) Standard Test Method for Soil and Rock Properties (ASCE 2013).

2.1.3 American Society of Civil Engineers (ASCE) Standard Test Method for Soil and Rock Properties (ASCE 2013).

### 3. Terminology

3.1 **Particle size distribution**—The distribution of particle sizes in a soil sample, expressed as a percentage of the total dry weight of the sample.

3.2 **Grain size distribution**—The distribution of particle sizes in a soil sample, expressed as a percentage of the total dry weight of the sample.

3.3 **Soil texture**—The distribution of particle sizes in a soil sample, expressed as a percentage of the total dry weight of the sample.

### 4. Summary of Test Method

4.1 The test method consists of the following steps: (1) preparation of the soil sample; (2) determination of the particle size distribution; (3) calculation of the soil texture; and (4) calculation of the grain size distribution.

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### 5. Significance and Use

5.1 This test method is used to determine the particle size distribution of soils, which is a fundamental property of soils. The results of this test are used to classify soils and to determine the soil texture and grain size distribution.

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## Standard Test Method for Particle-Size Analysis of Soils<sup>1</sup>

This standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

<sup>ε1</sup> NOTE—Section 19 was added editorially in September 1990.

### 1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-μm), or No. 200 (75-μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (1) a high-speed mechanical stirrer, and (2) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants<sup>2</sup>

E 11 Specification for Wire-Cloth Sieves for Testing Purposes<sup>3</sup>

E 100 Specification for ASTM Hydrometers<sup>4</sup>

### 3. Apparatus

3.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 *Stirring Apparatus*—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically oper-

ated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup<sup>5</sup> (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft<sup>3</sup>/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

<sup>2</sup> Current edition approved Nov. 21, 1963. Originally published 1935. Replaces D 422 - 62.

<sup>3</sup> Annual Book of ASTM Standards, Vol 04.08.

<sup>4</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>5</sup> Annual Book of ASTM Standards, Vol 14.03.

<sup>6</sup> Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Order Adjunct No. 12-404220-00.



# Section 1: Introduction

## Part 1: Overview of the Project

This document provides a comprehensive overview of the project, including its objectives, scope, and the roles of the various stakeholders involved. It is intended to serve as a reference for all project-related activities and to ensure that all team members are aligned with the project's goals and vision.

The project is a multi-phase endeavor that requires the coordination of resources, personnel, and information. The following sections will detail the project's structure, timeline, and the specific tasks and responsibilities assigned to each team member.

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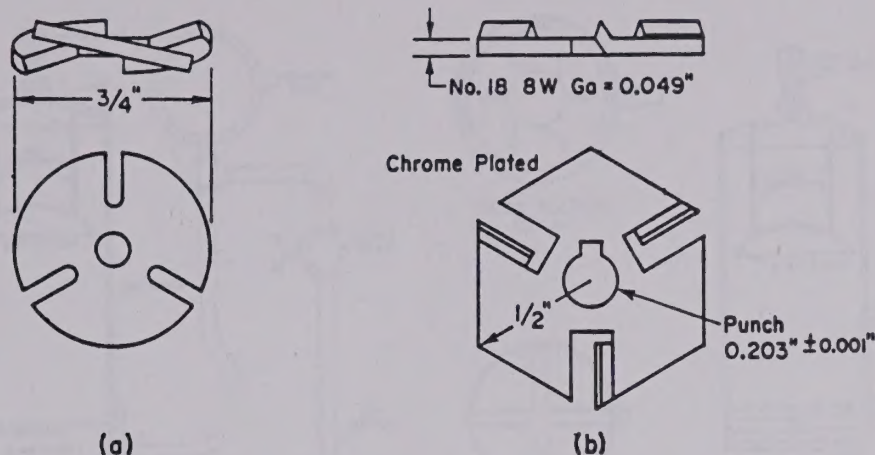
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Metric Equivalents					
in.	0.001	0.049	0.203	1/2	3/4
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles

3-in. (75-mm)	No. 10 (2.00-mm)
2-in. (50-mm)	No. 20 (850-μm)
1 1/2-in. (37.5-mm)	No. 40 (425-μm)
1-in. (25.0-mm)	No. 60 (250-μm)
3/4-in. (19.0-mm)	No. 140 (106-μm)
1/2-in. (9.5-mm)	No. 200 (75-μm)
No. 4 (4.75-mm)	

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)	No. 16 (1.18-mm)
1 1/2-in. (37.5-mm)	No. 30 (600-μm)
3/4-in. (19.0-mm)	No. 50 (300-μm)
1/2-in. (9.5-mm)	No. 100 (150-μm)
No. 4 (4.75-mm)	No. 200 (75-μm)
No. 8 (2.36-mm)	

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

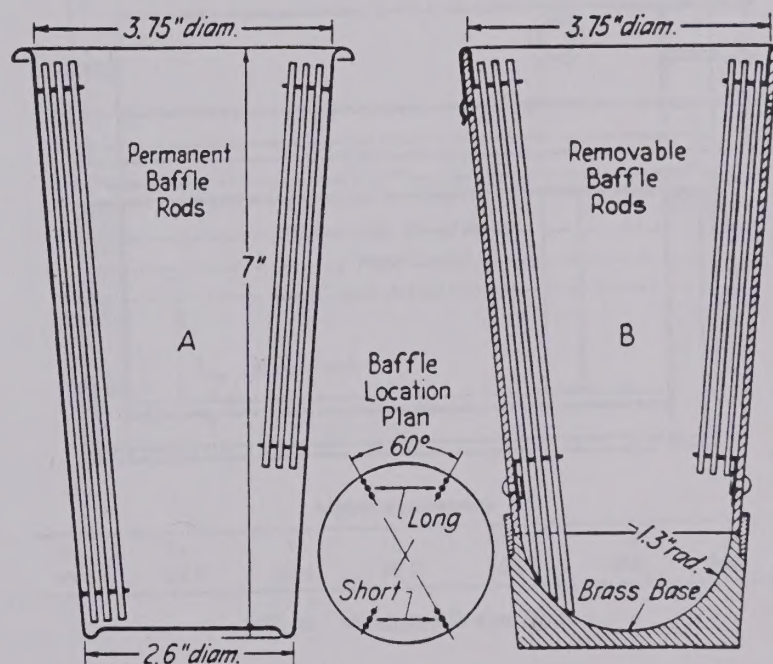
3.9 *Timing Device*—A watch or clock with a second hand.

#### 4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall



Metric Equivalents			
in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus

be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.







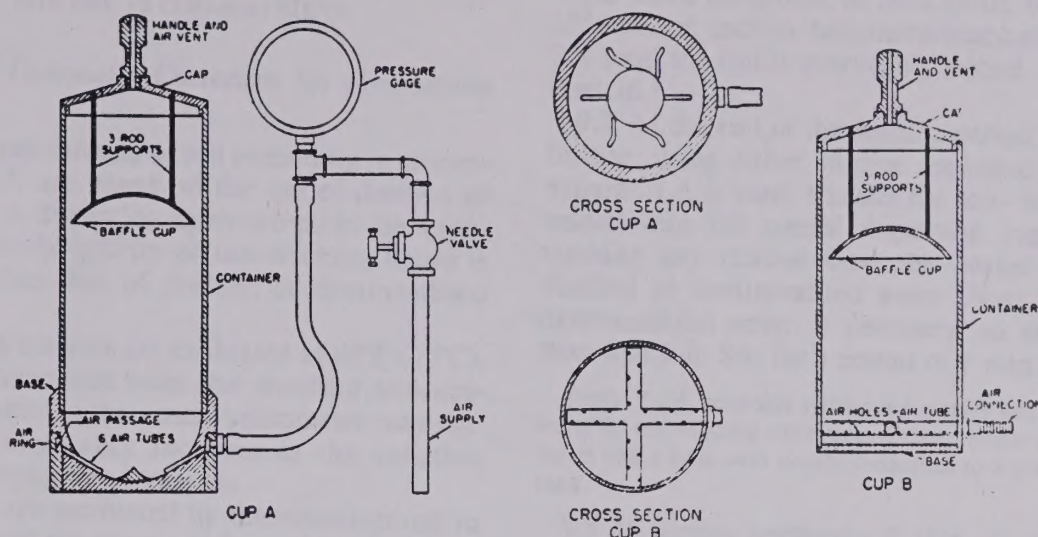


FIG. 3 Air-Jet Dispersion Cups of Apparatus B

## 5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
3/8 (9.5)	500
1/4 (19.0)	1000
1 (25.4)	2000
1 1/2 (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

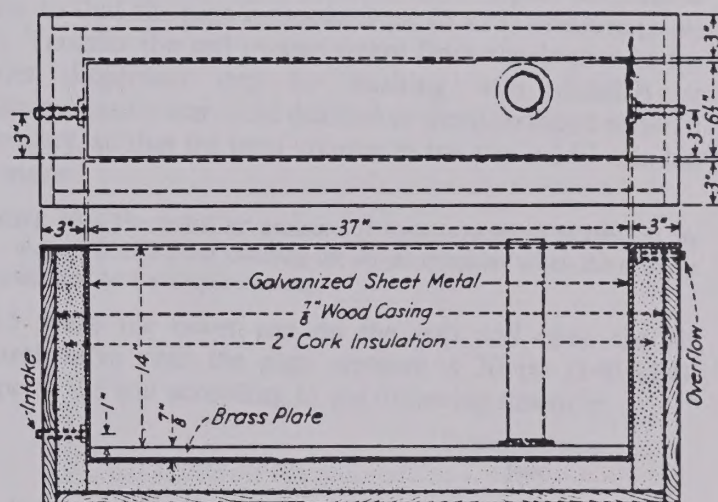
5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

## SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

## 6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm),



Metric Equivalents						
in.	7/8	1	3	6 1/4	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

2-in. (50-mm), 1 1/2-in. (37.5-mm), 1-in. (25.0-mm), 3/4-in. (19.0-mm), 3/8-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.





Fig. 1. Schematic diagram of the device.

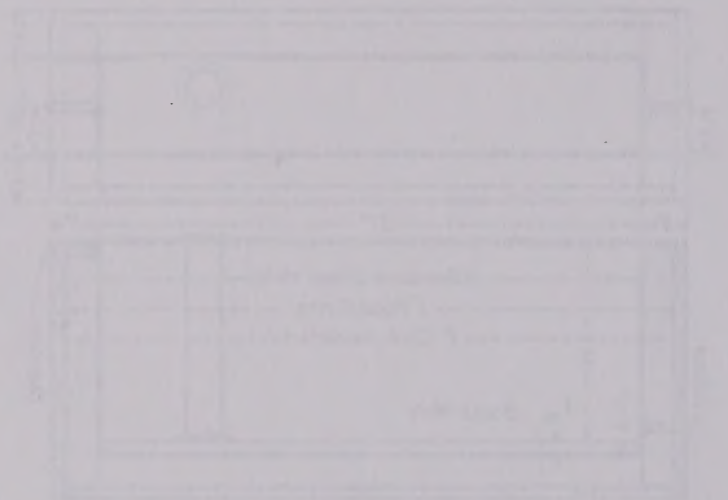


Fig. 2. Schematic diagram of the device.

The device is designed for the measurement of the pressure in the gas phase of a mixture of gases. It consists of a cylindrical body with a flange at the top and a base. The top view shows a circular cross-section with a central hole and radial lines. The cross-section view shows the internal structure of the component.

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Parameter	Value
Pressure	0.1 MPa
Temperature	20°C
Flow rate	10 L/min
Accuracy	±1%
Resolution	0.01 MPa
Range	0 to 1 MPa

The device is designed for the measurement of the pressure in the gas phase of a mixture of gases. It consists of a cylindrical body with a flange at the top and a base. The top view shows a circular cross-section with a central hole and radial lines. The cross-section view shows the internal structure of the component.

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# HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

## 7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

## 8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at  $230 \pm 9^\circ\text{F}$  ( $110 \pm 5^\circ\text{C}$ ), and weigh again. Record the masses.

## 9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

## 10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns.







Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

## 11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-μm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9°F (110 ± 5°C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

## CALCULATIONS AND REPORT

### 12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the 3/8-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the 3/8-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

### 13. Hygroscopic Moisture Correction Factor

13.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

### 14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10

**TABLE 1 Values of Correction Factor,  $\alpha$ , for Different Specific Gravities of Soil Particles<sup>a</sup>**

Specific Gravity	Correction Factor <sup>a</sup>
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

<sup>a</sup> For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

(2.00-mm) sieve, and multiplying the result by 100. This value is the weight  $W$  in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

$a$  = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

$P$  = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

$R$  = hydrometer reading with composite correction applied (Section 7),

$W$  = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,

$G$  = specific gravity of the soil particles, and

$G_1$  = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for  $R$  is based on a value of one for  $G_1$ .

### 15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30\pi/980(G - G_1)] \times L/T}$$

where:

$D$  = diameter of particle, mm,







- $n$  = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),
- $L$  = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2)),
- $T$  = interval of time from beginning of sedimentation to the taking of the reading, min,
- $G$  = specific gravity of soil particles, and
- $G_1$  = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

$K$  = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of  $K$  for a range of temperatures and specific gravities are given in Table 3. The value of  $K$  does not change for a series of readings constituting a test, while values of  $L$  and  $T$  do vary.

15.3 Values of  $D$  may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of  $L$  is divided by  $T$  using the  $A$ - and  $B$ -scales, the square root being indicated on the  $D$ -scale. Without ascertaining the value of the square root it may be multiplied by  $K$ , using either the  $C$ - or  $CI$ -scale.

## 16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

## 17. Graph

17.1 When the hydrometer analysis is performed, a graph

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes<sup>A</sup>

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

<sup>A</sup> Values of effective depth are calculated from the equation:

$$L = L_1 + \frac{1}{2} [L_2 - (V_B/A)]$$

where:

$L$  = effective depth, cm.

$L_1$  = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm.

$L_2$  = overall length of the hydrometer bulb, cm.

$V_B$  = volume of hydrometer bulb, cm<sup>3</sup>, and

$A$  = cross-sectional area of sedimentation cylinder, cm<sup>2</sup>

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

$L_2$  = 14.0 cm

$V_B$  = 67.0 cm<sup>3</sup>

$A$  = 27.8 cm<sup>2</sup>

For hydrometer 151H:

$L_1$  = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

For hydrometer 152H:

$L_1$  = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an







TABLE 3 Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

## 18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles.

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular.

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable.

18.1.4 Specific gravity, if unusually high or low.

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

- |  |         |
|--|---------|
| (1) Gravel, passing 3-in. and retained on No. 4 sieve              | ..... % |
| (2) Sand, passing No. 4 sieve and retained on No. 200 sieve        | ..... % |
| (a) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve  | ..... % |
| (b) Medium sand, passing No. 10 sieve and retained on No. 40 sieve | ..... % |
| (c) Fine sand, passing No. 40 sieve and retained on No. 200 sieve  | ..... % |
| (3) Silt size, 0.074 to 0.005 mm                                   | ..... % |
| (4) Clay size, smaller than 0.005 mm                               | ..... % |
| Colloids, smaller than 0.001 mm                                    | ..... % |

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

### SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.	.....
2-in.	.....
1½-in.	.....
1-in.	.....
¾-in.	.....
½-in.	.....
No. 4 (4.75-mm)	.....
No. 10 (2.00-mm)	.....
No. 40 (425-µm)	.....
No. 200 (75-µm)	.....

### HYDROMETER ANALYSIS

0.074 mm  
0.005 mm  
0.001 mm

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-µm) sieves may be substituted for No. 10 and No. 40 sieves.

## 19. Keywords

19.1 grain-size; hydrometer analysis; hygroscopic moisture; particle-size; sieve analysis

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*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.*



TABLE 2. Values of  $\chi^2$  for the  $\chi^2$  test of independence for the  $2 \times 2$  contingency table.

df	Significance level, $\alpha$									
	0.10	0.05	0.025	0.01	0.005	0.001	0.0005	0.0001	0.00005	0.00001
1	2.706	3.841	5.024	7.879	8.445	10.828	11.337	13.801	15.493	17.535
2	4.605	5.991	7.378	10.597	11.578	13.816	14.441	17.000	18.475	20.493
3	6.251	7.378	9.348	12.838	13.816	16.266	16.928	19.488	21.024	23.337
4	7.779	8.983	10.597	14.441	15.557	17.709	18.475	21.024	22.981	25.188
5	9.236	10.237	11.968	15.086	16.750	18.549	19.367	22.302	24.154	26.893
6	10.597	11.578	13.201	15.812	17.535	19.367	20.278	23.435	25.188	28.289
7	11.968	12.838	14.441	16.519	18.475	20.278	21.201	24.478	26.186	29.701
8	13.201	14.067	15.557	17.155	19.367	21.201	22.154	25.524	27.154	31.024
9	14.441	15.190	16.691	17.709	20.278	22.154	23.024	26.564	28.137	32.358
10	15.557	16.329	17.709	18.307	21.201	23.024	23.981	27.587	29.190	33.578
11	16.691	17.338	18.672	18.885	22.154	23.981	24.928	28.599	30.213	34.701
12	17.709	18.307	19.579	19.433	23.024	24.928	25.867	29.591	31.216	35.718
13	18.672	19.216	20.409	19.951	23.981	25.867	26.791	30.578	32.190	36.718
14	19.579	20.064	21.199	20.449	24.928	26.791	27.701	31.549	33.143	37.690
15	20.409	20.841	21.900	20.927	25.867	27.701	28.599	32.493	34.078	38.578
16	21.199	21.559	22.561	21.385	26.791	28.599	29.481	33.416	34.993	39.475
17	21.900	22.237	23.185	21.823	27.701	29.481	30.367	34.316	35.885	40.378
18	22.561	22.878	23.772	22.241	28.599	30.367	31.243	35.190	36.754	41.278
19	23.185	23.485	24.330	22.641	29.481	31.243	32.109	36.043	37.601	42.175
20	23.772	24.064	24.855	23.024	30.367	32.109	32.967	36.878	38.427	43.064
21	24.330	24.617	25.350	23.393	31.243	32.967	33.816	37.690	39.237	43.943
22	24.855	25.154	25.816	23.747	32.109	33.816	34.654	38.478	40.024	44.816
23	25.350	25.667	26.254	24.086	32.967	34.654	35.481	39.243	40.793	45.685
24	25.816	26.159	26.667	24.411	33.816	35.481	36.293	40.024	41.543	46.543
25	26.254	26.625	27.054	24.723	34.654	36.293	37.093	40.793	42.278	47.393
26	26.667	27.067	27.416	25.024	35.481	37.093	37.885	41.543	43.000	48.237
27	27.054	27.485	27.754	25.312	36.293	37.885	38.667	42.278	43.709	49.078
28	27.416	27.885	28.067	25.586	37.093	38.667	39.433	43.000	44.409	49.909
29	27.754	28.267	28.354	25.847	37.885	39.433	40.185	43.709	45.093	50.727
30	28.067	28.625	28.616	26.093	38.667	40.185	40.927	44.409	45.767	51.537
31	28.354	28.967	28.854	26.323	39.433	40.927	41.654	45.093	46.427	52.337
32	28.616	29.293	29.067	26.537	40.185	41.654	42.367	45.767	47.078	53.127
33	28.854	29.600	29.254	26.737	40.927	42.367	43.067	46.427	47.716	53.909
34	29.067	29.885	29.416	26.923	41.654	43.067	43.754	47.078	48.343	54.678
35	29.254	30.154	29.554	27.093	42.367	43.754	44.427	47.716	48.954	55.437
36	29.416	30.409	29.667	27.247	43.067	44.427	45.085	48.343	49.543	56.185
37	29.554	30.654	29.767	27.385	43.754	45.085	45.727	48.954	50.116	56.916
38	29.667	30.885	29.843	27.509	44.427	45.727	46.354	49.543	50.678	57.637
39	29.767	31.100	29.900	27.616	45.085	46.354	46.967	50.116	51.227	58.343
40	29.843	31.293	29.943	27.709	45.727	46.967	47.567	50.678	51.754	59.037
41	29.900	31.467	29.972	27.785	46.354	47.567	48.154	51.227	52.267	59.716
42	29.943	31.625	30.000	27.847	46.967	48.154	48.727	51.754	52.767	60.385
43	29.972	31.767	30.016	27.893	47.567	48.727	49.285	52.267	53.254	61.037
44	29.972	31.893	30.024	27.927	48.154	49.285	49.827	52.767	53.727	61.678
45	29.972	32.009	30.024	27.947	48.727	49.827	50.354	53.254	54.185	62.309
46	29.972	32.116	30.024	27.954	49.285	50.354	50.867	53.727	54.627	62.927
47	29.972	32.216	30.024	27.954	49.827	50.867	51.367	54.185	55.054	63.537
48	29.972	32.312	30.024	27.954	50.354	51.367	51.854	54.627	55.467	64.137
49	29.972	32.400	30.024	27.954	50.867	51.854	52.327	55.054	55.867	64.727
50	29.972	32.481	30.024	27.954	51.367	52.327	52.785	55.467	56.254	65.309

15.1. The  $\chi^2$  test is used to test the hypothesis that the observed frequencies are equal to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.2. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are proportional to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.3. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are independent of the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.4. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are equal to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.5. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are proportional to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.6. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are independent of the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.7. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are equal to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.8. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are proportional to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.9. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are independent of the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.

15.10. The  $\chi^2$  test is also used to test the hypothesis that the observed frequencies are equal to the expected frequencies. The test is based on the  $\chi^2$  statistic, which is calculated as follows:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where  $O$  is the observed frequency and  $E$  is the expected frequency. The test is then compared to the critical value of  $\chi^2$  for the given degrees of freedom and significance level. If the calculated  $\chi^2$  is greater than the critical value, the null hypothesis is rejected.





## Standard Practice for Thin-Walled Tube Sampling of Soils<sup>1</sup>

This standard is issued under the fixed designation D 1587; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This practice has been approved for use by agencies of the Department of Defense and for listing in the DOD Index of Specifications and Standards.*

### 1. Scope

1.1 This practice covers a procedure for using a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests of structural properties. Thin-walled tubes used in piston, plug, or rotary-type samplers, such as the Denison or Pitcher, must comply with the portions of this practice which describe the thin-walled tubes (5.3).

NOTE 1—This practice does not apply to liners used within the above samplers.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>2</sup>

D 3550 Practice for Ring-Lined Barrel Sampling of Soils<sup>2</sup>

D 4220 Practices for Preserving and Transporting Soil Samples<sup>2</sup>

### 3. Summary of Practice

3.1 A relatively undisturbed sample is obtained by pressing a thin-walled metal tube into the in-situ soil, removing the soil-filled tube, and sealing the ends to prevent the soil from being disturbed or losing moisture.

### 4. Significance and Use

4.1 This practice, or Practice D 3550, is used when it is necessary to obtain a relatively undisturbed specimen suitable for laboratory tests of structural properties or other tests that might be influenced by soil disturbance.

### 5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment may be used that provides a reasonably clean hole; that does not disturb the soil to be sampled; and that does not hinder the penetration of the thin-walled sampler. Open borehole diameter and the inside diameter of driven casing or hollow stem auger shall not exceed 3.5 times the outside diameter of the thin-walled tube.

5.2 *Sampler Insertion Equipment*, shall be adequate to provide a relatively rapid continuous penetration force. For

hard formations it may be necessary, although not recommended, to drive the thin-walled tube sampler.

5.3 *Thin-Walled Tubes*, should be manufactured as shown in Fig. 1. They should have an outside diameter of 2 to 5 in. and be made of metal having adequate strength for use in the soil and formation intended. Tubes shall be clean and free of all surface irregularities including projecting weld seams.

5.3.1 *Length of Tubes*—See Table 1 and 6.4.

5.3.2 *Tolerances*, shall be within the limits shown in Table 2.

5.3.3 *Inside Clearance Ratio*, should be 1 % or as specified by the engineer or geologist for the soil and formation to be sampled. Generally, the inside clearance ratio used should increase with the increase in plasticity of the soil being sampled. See Fig. 1 for definition of inside clearance ratio.

5.3.4 *Corrosion Protection*—Corrosion, whether from galvanic or chemical reaction, can damage or destroy both the thin-walled tube and the sample. Severity of damage is a function of time as well as interaction between the sample and the tube. Thin-walled tubes should have some form of protective coating. Tubes which will contain samples for more than 72 h shall be coated. The type of coating to be used may vary depending upon the material to be sampled. Coatings may include a light coat of lubricating oil, lacquer, epoxy, Teflon, and others. Type of coating must be specified by the engineer or geologist if storage will exceed 72 h. Plating of the tubes or alternate base metals may be specified by the engineer or geologist.

5.4 *Sampler Head*, serves to couple the thin-walled tube to the insertion equipment and, together with the thin-walled tube, comprises the thin-walled tube sampler. The sampler head shall contain a suitable check valve and a venting area to the outside equal to or greater than the area through the check valve. Attachment of the head to the tube shall be concentric and coaxial to assure uniform application of force to the tube by the sampler insertion equipment.

### 6. Procedure

6.1 Clean out the borehole to sampling elevation using whatever method is preferred that will ensure the material to be sampled is not disturbed. If groundwater is encountered, maintain the liquid level in the borehole at or above ground water level during the sampling operation.

6.2 Bottom discharge bits are not permitted. Side discharge bits may be used, with caution. Jetting through an open-tube sampler to clean out the borehole to sampling elevation is not permitted. Remove loose material from the center of a casing or hollow stem auger as carefully as

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

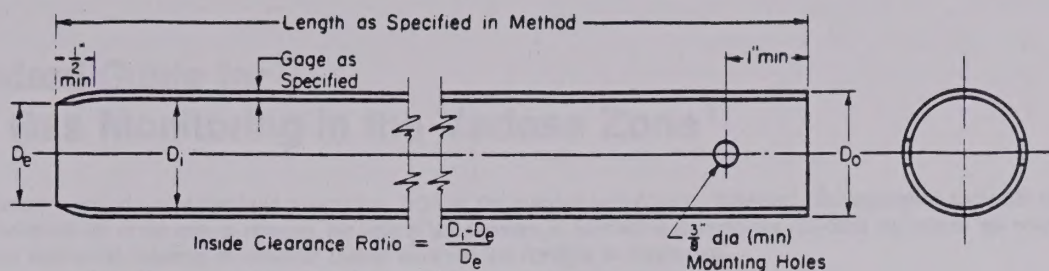
Current edition approved Aug. 17, 1983. Published October 1983. Originally published as D 1587 - 58 T. Last previous edition D 1587 - 74.

<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.08.









- NOTE 1—Minimum of two mounting holes on opposite sides for 2 to 3½ in. sampler.  
 NOTE 2—Minimum of four mounting holes spaced at 90° for samplers 4 in. and larger.  
 NOTE 3—Tube held with hardened screws.  
 NOTE 4—Two-inch outside-diameter tubes are specified with an 18-gage wall thickness to comply with area ratio criteria accepted for "undisturbed samples." Users are advised that such tubing is difficult to locate and can be extremely expensive in small quantities. Sixteen-gage tubes are generally readily available.

Metric Equivalents

in.	mm
¾	6.77
½	12.7
1	25.4
2	50.8
3½	88.9
4	101.6

FIG. 1 Thin-Walled Tube for Sampling

TABLE 1 Suitable Thin-Walled Steel Sample Tubes<sup>A</sup>

Outside diameter:			
2 in.	2	3	5
mm	50.8	76.2	127
Wall thickness:			
Bwg	18	16	11
in.	0.049	0.065	0.120
mm	1.24	1.65	3.05
Tube length:			
in.	36	36	54
m	0.91	0.91	1.45
Clearance ratio, %	1	1	1

<sup>A</sup> The three diameters recommended in Table 1 are indicated for purposes of standardization, and are not intended to indicate that sampling tubes of intermediate or larger diameters are not acceptable. Lengths of tubes shown are illustrative. Proper lengths to be determined as suited to field conditions.

TABLE 2 Dimensional Tolerances for Thin-Walled Tubes

Nominal Tube Diameters from Table 1 <sup>A</sup> Tolerances, in.			
Size Outside Diameter	2	3	5
Outside diameter	+0.007 -0.000	+0.010 -0.000	+0.015 -0.000
Inside diameter	+0.000 -0.007	+0.000 -0.010	+0.000 -0.015
Wall thickness	±0.007	±0.010	±0.015
Ovality	0.015	0.020	0.030
Straightness	0.030/ft	0.030/ft	0.030/ft

<sup>A</sup> Intermediate or larger diameters should be proportional. Tolerances shown are essentially standard commercial manufacturing tolerances for seamless steel mechanical tubing. Specify only two of the first three tolerances; that is, O.D. and I.D., or O.D. and Wall, or I.D. and Wall.

possible to avoid disturbance of the material to be sampled.

NOTE 2—Roller bits are available in downward-jetting and diffused-jet configurations. Downward-jetting configuration rock bits are not acceptable. Diffuse-jet configurations are generally acceptable.

6.3 Place the sample tube so that its bottom rests on the bottom of the hole. Advance the sampler without rotation by a continuous relatively rapid motion.

6.4 Determine the length of advance by the resistance and condition of the formation, but the length shall never exceed

5 to 10 diameters of the tube in sands and 10 to 15 diameters of the tube in clays.

NOTE 3—Weight of sample, laboratory handling capabilities, transportation problems, and commercial availability of tubes will generally limit maximum practical lengths to those shown in Table 1.

6.5 When the formation is too hard for push-type insertion, the tube may be driven or Practice D 3550 may be used. Other methods, as directed by the engineer or geologist, may be used. If driving methods are used, the data regarding weight and fall of the hammer and penetration achieved must be shown in the report. Additionally, that tube must be prominently labeled a "driven sample."

6.6 In no case shall a length of advance be greater than the sample-tube length minus an allowance for the sampler head and a minimum of 3 in. for sludge-end cuttings.

NOTE 4—The tube may be rotated to shear bottom of the sample after pressing is complete.

6.7 Withdraw the sampler from the formation as carefully as possible in order to minimize disturbance of the sample.

## 7. Preparation for Shipment

7.1 Upon removal of the tube, measure the length of sample in the tube. Remove the disturbed material in the upper end of the tube and measure the length again. Seal the upper end of the tube. Remove at least 1 in. of material from the lower end of the tube. Use this material for soil description in accordance with Practice D 2488. Measure the overall sample length. Seal the lower end of the tube. Alternatively, after measurement, the tube may be sealed without removal of soil from the ends of the tube if so directed by the engineer or geologist.

NOTE 5—Field extrusion and packaging of extruded samples under the specific direction of a geotechnical engineer or geologist is permitted.

NOTE 6—Tubes sealed over the ends as opposed to those sealed with expanding packers should contain end padding in end voids in order to prevent drainage or movement of the sample within the tube.

7.2 Prepare and immediately affix labels or apply markings as necessary to identify the sample. Assure that the









# Standard Guide for Soil Gas Monitoring in the Vadose Zone<sup>1</sup>

This standard is issued under the fixed designation D 5314; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This guide covers information pertaining to a broad spectrum of practices and applications of soil atmosphere sampling, including sample recovery and handling, sample analysis, data interpretation, and data reporting. This guide can increase the awareness of soil gas monitoring practitioners concerning important aspects of the behavior of the soil-water-gas-contaminant system in which this monitoring is performed, as well as inform them of the variety of available techniques of each aspect of the practice. Appropriate applications of soil gas monitoring are identified, as are the purposes of the various applications. Emphasis is placed on soil gas contaminant determinations in certain application examples.

1.2 This guide suggests a variety of approaches useful to successfully monitor vadose zone contaminants with instructions that offer direction to those who generate and use soil gas data.

1.3 This guide does not recommend a standard practice to follow in all cases nor does it recommend definite courses of action. The success of any one soil gas monitoring methodology is strongly dependent upon the environment in which it is applied.

1.4 Concerns of practitioner liability or protection from or release from such liability, or both, are not addressed by this guide.

1.5 This guide is organized into the following sections and subsections that address specific segments of the practice of monitoring soil gas:

### Section

- 4 Summary of Practice
- 4.1 Basic principles, including partitioning theory, migration and emplacement processes, and contaminant degradation
- 4.7 Summary Procedure
- 5 Significance and Use
- 6 Approach and Procedure
- 6.1 Sampling Methodology
- 6.5 Sample Handling and Transport
- 6.6 Analysis of Soil Gas Samples
- 6.7 Data Interpretation
- 7 Reporting

1.6 *This guide does not purport to set standard levels of acceptable risk. Use of this guide for purposes of risk assessment is wholly the responsibility of the user.*

1.7 The values stated in either inch-pound or SI units are to be regarded separately as the standard. The values given in parentheses are for information only.

1.8 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
- D 1356 Terminology Relating to Atmospheric Sampling and Analysis<sup>3</sup>
- D 1357 Practice for Planning the Sampling of the Ambient Atmosphere<sup>3</sup>
- D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>
- D 1605 Practices for Sampling Atmospheres for Analysis of Gases and Vapors<sup>3</sup>
- D 1914 Practice for Conversion Units and Factors Relating to Atmospheric Analysis<sup>3</sup>
- D 2652 Terminology Relating to Activated Carbon<sup>4</sup>
- D 2820 Test Method for C<sub>1</sub> Through C<sub>5</sub> Hydrocarbons in the Atmosphere by Gas Chromatography<sup>3</sup>
- D 3249 Practice for General Ambient Air Analyzer Procedures<sup>3</sup>
- D 3416 Test Method for Total Hydrocarbons, Methane, and Carbon Monoxide (Gas Chromatographic Method) in the Atmosphere<sup>3</sup>
- D 3584 Practice for Indexing Papers and Reports on Soil and Rock for Engineering Purposes<sup>2</sup>
- D 3614 Guide for Laboratories Engaged in Sampling and Analysis of Atmospheres and Emissions<sup>3</sup>
- D 3670 Guide for Determination of Precision and Bias of Methods of Committee D-22<sup>3</sup>
- D 3686 Practice for Sampling Atmospheres to Collect Organic Compound Vapors (Activated Charcoal Tube Adsorption Method)<sup>3</sup>
- D 3687 Practice for Analysis of Organic Compound Vapors Collected by the Activated Charcoal Tube Adsorption Method<sup>3</sup>
- D 4220 Practices for Preserving and Transporting Soil Samples<sup>2</sup>
- D 4490 Practice for Measuring the Concentration of Toxic Gases or Vapors Using Detector Tubes<sup>3</sup>

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 04.08.

<sup>3</sup> Annual Book of ASTM Standards, Vol 11.03.

<sup>4</sup> Annual Book of ASTM Standards, Vol 15.01.







- D 4597 Practice for Sampling Workplace Atmospheres to Collect Organic Gases or Vapors with Activated Charcoal Diffusional Samplers<sup>3</sup>
- D 4696 Guide for Pore-Liquid Sampling from the Vadose Zone<sup>2</sup>
- D 4700 Guide for Soil Core Sampling from the Vadose Zone<sup>2</sup>
- D 5088 Practice for the Decontamination of Field Equipment Used at Non Radioactive Waste Sites<sup>5</sup>
- E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods<sup>6</sup>
- E 260 Practice for Packed Column Gas Chromatography<sup>7</sup>
- E 355 Practice for Gas Chromatography Terms and Relationships<sup>7</sup>
- E 594 Practice for Testing Flame Ionization Detectors Used in Gas Chromatography<sup>7</sup>
- E 697 Practice for Use of Electron-Capture Detectors in Gas Chromatography<sup>7</sup>

### 3. Terminology

#### 3.1 Descriptions of Terms Specific to This Standard:

3.1.1 *capillary fringe*—the basal region of the vadose zone comprising sediments that are saturated, or nearly saturated, near the water table, gradually decreasing in water content with increasing elevation above the water table. Also see Terminology D 653.

3.1.2 *contaminant*—substances not normally found in an environment at the observed concentration.

3.1.3 *emplacement*—the establishment of contaminant residence in the vadose zone in a particular phase.

3.1.4 *free product*—liquid phase contaminants released into the environment.

3.1.5 *free vapor phase*—a condition of contaminant residence in which volatilized contaminants occur in porosity that is effective to free and open gaseous flow and exchange, such porosity generally being macroporosity.

3.1.6 *liquid phase*—contaminant residing as a liquid in vadose zone pore space, often referred to as “free product.”

3.1.7 *macroporosity*—large intergranular porosity with large pore throats, including soil cracks, moldic porosity, animal burrows and other significant void space.

3.1.8 *microporosity*—intragranular porosity and microscopic intergranular porosity with submicroscopic pore throats.

3.1.9 *occluded vapor phase*—condition of contaminant residence in which volatilized contaminants occur in porosity that is ineffective to free and open gaseous flow and exchange, such porosity generally being microporosity; frequently termed dead-end pore space.

3.1.10 *partitioning*—the act of movement of contaminants from one soil residence phase to another.

3.1.11 *soil gas*—vadose zone atmosphere.

3.1.12 *solute phase*—a condition of contaminant residence in which contaminants are dissolved in ground water in either the saturated or the vadose zone.

3.1.13 *sorbed phase*—a condition of contaminant residence in which contaminants are adsorbed onto the surface

of soil particles or absorbed by soil organic matter.

3.1.14 *vadose zone*—the hydrogeological region extending from the soil surface to the top of the principal water table.

### 4. Summary of Guide

4.1 Soil gas monitoring in the vadose zone is a method used to directly measure characteristics of the soil atmosphere that are frequently utilized as an indirect indicator of processes occurring in and below a sampling horizon. Soil gas monitoring is used as a method to suggest the presence, composition, and origin of contaminants in and below the vadose zone. Among other applications, this method is also employed in the exploration for natural resources, including petroleum, natural gas and precious metals. Soil gas monitoring is a valuable screening method for detection of volatile organic contaminants, the most abundant analytical group of ground-water contaminant compounds (1).<sup>8</sup>

4.2 *Basic Theoretical Principles*—The processes indicated by the soil gas monitoring method are partitioning, migration, emplacement and degradation. Partitioning represents a group of processes that control contaminant movement from one physical phase to another, these phases being liquid, free vapor (that is, through-flowing air (2)), occluded vapor (that is, locally accessible air and trapped air (2)), solute and sorbed. Migration refers to contaminant movement over distance with any vertical, horizontal or temporal component. Emplacement refers to establishment of contaminant residence in any phase within any residence opportunity. Degradation is the process whereby contaminants are attenuated by oxidation or reduction in the vadose zone, either through biogenic or abiogenic processes. Soil gas monitoring measures the result of the interaction of these processes in a dynamic equilibrium. Measurement of these processes in static equilibrium is unrealistic.

4.3 The following subsections provide detailed information on partitioning, migration, emplacement and degradation. Subsection 4.4 provides a summary procedure for soil gas sampling. Users of this guide who do not wish to study details of partitioning, migration, emplacement and degradation at this time may skip to 4.4.

4.3.1 Partitioning is the initial step by which contaminants begin to move away from their source. Partitioning occurs in water saturated and unsaturated environments. This group of processes is complex and difficult to quantify when considered in the vadose zone due to the unique makeup of the vadose matrix, i.e. air-filled porosity (microporous and macroporous), pore water, free product, solid-phase soil organic matter, clay and discrete inorganic soil particles. Important individual processes of partitioning are dissolution, volatilization, air-water partitioning, soil-water partitioning and soil-air partitioning (3).

4.3.2 Dissolution is the process whereby volatile contaminants move between the liquid phase (free product) and the solute phase (dissolved in water). At equilibrium, the product of the mole fraction of a particular compound in the liquid phase and the activity coefficient of that compound in the liquid phase is equal to the product of the mole fraction of

<sup>5</sup> Annual Book of ASTM Standards, Vol 04.09.

<sup>6</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>7</sup> Annual Book of ASTM Standards, Vol 14.01.

<sup>8</sup> The boldface numbers given in parentheses refer to a list of references at the end of the text.







that compound in the solute phase and the activity coefficient of that compound in the solute phase. This process is more clearly described by the following expression:

$$X^L_I \Gamma^L_I = X^W_I \Gamma^W_I \quad (1)$$

where:

$X^L_I$  = the mole fraction of compound (*I*) in the liquid (*L*) phase (free product),

$X^W_I$  = the mole fraction of compound (*I*) in the solute (*W*) phase (dissolved in water),

$\Gamma^L_I$  = the activity coefficient of compound (*I*) in the liquid (*L*) phase (free product), and

$\Gamma^W_I$  = the activity coefficient of compound (*I*) in the solute (*W*) phase (dissolved in water).

Dissolution equilibrium is therefore influenced by concentration of the subject compound in both the free product contaminant mixture and water. The most common practical application of expression Eq (1) in soil gas monitoring is in hydrocarbon detection. Simplification of Eq (1) is achieved by the following:

assume:

$$\Gamma^W_I = 1/S_I$$

where:

$S$  = the solubility of compound (*I*) in water

and:

$$\Gamma^L_I = 1, \text{ acceptable for hydrocarbons (3),}$$

then:

$$X^W_I = X^L_I S_I \quad (2)$$

4.3.2.1 Dissolution equilibrium is impacted by the presence of liquid phase cosolvents, such as gasoline additives, at low concentrations in liquid phase mixtures. This change in dissolution equilibrium can enhance the solubility of certain liquid phase components in water beyond what is indicated by partitioning coefficient data generated in the laboratory. This can have significant impact on downstream concentrations of the contaminant(s) in the soil atmosphere.

4.3.2.2 The effects of temperature upon dissolution equilibrium are generally insignificant for aliphatic hydrocarbons between 15 and 50°C (4), the temperature range from which most soil gas samples are recovered. However, temperature effects upon dissolution equilibrium can be significant for other common families of contaminant compounds within similar temperature ranges (5). These effects must be considered when planning or interpreting the results of a soil gas survey.

4.3.2.3 Dissolution equilibrium is altered by changes in water salinity. Modest decreases in the solubility of contaminants in water are to be expected with increases in salinity of the solution.

4.3.2.4 The rate of dissolution is strongly dependent upon the partitioning coefficient of the particular contaminant of interest and the amount of mixing of the liquid phase and water (3). For example, partitioning of a particular contaminant into ground water is accelerated by frequent water level fluctuations within a contaminated capillary fringe. The downstream implications for subsequent partitioning of the contaminant from the solute to the vapor phase for eventual soil gas recovery are obvious.

4.3.3 Volatilization is the process during which volatile contaminants move between the liquid phase (free product)

or solute phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. Contaminant mixtures can contain compounds with a considerable range of vapor pressures that can contribute contaminants to the soil atmosphere by volatilization. This atmosphere will exhibit a composition similar to that of the parent contaminant but lacking in those constituents with the lowest vapor pressures. The likelihood of the presence of a particular contaminant introduced into the soil atmosphere by volatilization can be estimated by considering the partial pressure of that contaminant in a vapor phase. This partial pressure is equal to the product of the mole fraction concentration of the subject component in the liquid contaminant solution, the activity coefficient of the subject component and the vapor pressure of the pure component. This concept is more clearly expressed as follows:

$$P = X_I \Gamma_I P^o \quad (3)$$

where:

$P$  = the partial pressure of the subject contaminant compound in the vapor phase,

$X_I$  = the mole fraction concentration of contaminant (*I*) in the liquid contaminant solution,

$\Gamma_I$  = the activity coefficient of the subject contaminant in the liquid contaminant solution, and

$P^o$  = the vapor pressure of the pure component.

4.3.3.1 The quantity of contaminant volatilized into a vapor phase and the rate of that process is strongly dependent upon temperature. Rate of volatilization is also controlled by the rate of transport of contaminant vapors from the liquid phase-vapor phase interface (3). This rate is probably higher when macroporous flow paths are available for vapor phase transport, and is promoted by a number of driving forces. These are concentration gradient, density gradient between soil atmosphere and contaminant-saturated soil atmosphere, convection currents related to temperature gradient, barometric pressure pumping and introduction of water onto the liquid phase-vapor phase interface.

4.3.4 Air-water partitioning is the process by which volatile contaminants move between the solute phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. For dilute solutions, air-water partitioning is controlled by Henry's Law, which states that the vapor pressure of a volatile compound above a dilute aqueous solution of that compound is equal to the product of the Henry's Law constant and the mole fraction of that compound in the aqueous solution. Henry's Law may be represented as:

$$P_I = k X_{I(aq)} \quad (4)$$

where:

$P_I$  = vapor pressure of compound (*I*) above a dilute aqueous solution of (*I*),

$k$  = the Henry's Law constant for compound (*I*) at a given temperature, and

$X_{I(aq)}$  = the mole fraction of the subject contaminant compound in the aqueous solution.

Care must be exercised in using Henry's Law to approximate contaminant vapor pressures because of unknowns related to the concentration of contaminants in solution and the contribution of other partitioning processes. Some available literature pertaining to soil gas surveying places emphasis on







Henry's Law constant at 25°C and atmospheric pressure as a primary controlling factor in determining the suitability of a particular volatile contaminant to the soil gas monitoring method. Such emphasis may be inappropriate when, for example, free product is the source of contaminant vapors or when contaminants have not reached ground water. Care must also be exercised in noting the units in which Henry's Law constants are expressed, as these vary from source to source. Volatile but very highly water soluble compounds behaving according to Henry's Law may not be detectable in soil gas because of their persistence for residence in the solute phase (6).

4.3.5 Soil-water partitioning is the process by which volatile contaminants move between the sorbed phase and the solute phase. This process is generally underestimated in its importance to the success or failure of contaminant recovery by soil gas sampling, especially when utilizing the majority of active soil gas sampling techniques generally available to field personnel.<sup>9</sup> There is uncertainty with respect to factors controlling soil-water partitioning, creating doubt as to the reliability of soil sorption data in most applications. Problems with soil sorption data include variability in measurement protocols, the variable nature of organic matter in soils, the effect of dissolved organic matter, unusual pH effects and the effect of salinity, among others (3).

4.3.5.1 The contribution of soil-water partitioning to contaminant phase residence equilibria is strongly controlled by sorbed contaminant concentration in soil, soil makeup, vadose zone pore water content, and soil porosity configuration. Important variables in soil makeup are the quantity, type and distribution of clay in soil and the quantity, type and distribution of soil organic matter. These variables impact the surface area available to sorptive processes, that is, the storage capacity of the soil for contaminants in the sorbed phase, and the pH of the sorption environment. Variations in vadose zone pore water content directly affect the storage capacity of the soil for contaminants in the solute phase. Soil porosity configuration, principally microporosity versus macroporosity, is critical to the rate of soil-water partitioning due to the contrast in surface area between micropores and macropores and the related storage capacity of this porosity for both pore water and sorbed contaminants.

4.3.6 Soil-air partitioning is the process by which volatile contaminants move between the sorbed phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. Like soil-water partitioning, this process is underestimated in its importance to the recoverability of contaminants by many soil gas sampling techniques. In vadose zone horizons with very low pore water contents, soil-air partitioning can yield vapor phase contaminant composition that differs from free product composition. In vadose zone horizons with higher pore water content, the responsibility for this compositional inconsistency is shared, largely with soil-water partitioning. In wet soil conditions, threshold soil water content values exist for trapped soil atmosphere content to become significant (7), suggesting that

responsibility for this compositional inconsistency can be largely attributed to occluded phase residence. Additional important variables are soil clay content, type and distribution, and soil organic matter content, type and distribution. Studies have demonstrated significant impact of soil organic matter and clay content on volatile organic compound emissions from soils (8). Due to the strong control on vapor phase contaminant content by the soil-air partitioning process, it is unreasonable to expect soil contaminants with high affinity for sorption to be efficiently recovered by most soil gas sampling techniques.

4.4 Migration of contaminants in the vadose zone, that is, unsaturated flow, is highly complex and is controlled by soil characteristics, contaminant composition and contaminant phase (9). Migration through unsaturated matrix can occur through a variety of diffusion, dispersion and mass transport mechanisms which behave in a manner unique to saturated flow.

4.4.1 A major division in migratory behavior of contaminants is defined by their solubility or immiscibility in water. Contaminants are often introduced into the soil as liquid mixtures, the components of which immediately begin to partition into other phases upon soil entry. Contaminants that establish soil residence behind a migratory front change in composition with distance from their point of entry. As contaminant migration continues, pathways for individual components can become divergent, such that the composition of the liquid mixture continues to change as migration proceeds. Eventually, migration of liquid mixtures may reach ground water. This can be retarded if the contaminants partition into other phases before reaching ground water and if contaminant vapor is less dense than the uncontaminated soil atmosphere. Transport of contaminants by downward percolation of meteoric waters and upward movement of ground water accelerate the contact of contaminants with ground water. When these contaminants do reach ground water, a radically different set of migration mechanisms begins to govern contaminant transport via saturated flow. Further divergence of contaminant pathways is dependent upon the tendency of each component of the contaminant mixture to float on ground water, become dissolved in ground water or sink to an impermeable layer within the aquifer. Detailed descriptions of these phenomena are available in the literature (10).

4.4.2 The impact of migration processes on soil gas measurement is significant. Although it is impractical to estimate actual migration mechanisms by modelling prior to most soil gas monitoring efforts, a rudimentary knowledge of site characteristics can guide investigators to realistic interpretations of soil gas data expressing unusual or highly variable compositions. More thorough knowledge of relevant site characteristics, such as the presence or absence of barriers to vertical or horizontal migration, that is, foundations, buried pavement, or perched ground water, as well as preferential pathways for contaminant migration, that is, backfill rubble, utility vaults, storm sewers or soil cracks, can assist investigators to assess the migration impact on soil gas survey design.

4.5 The vadose zone is a highly complex soil-air-water-hydrocarbon system with abundant opportunity to store contaminants in all phases. Contaminants partition ac-

<sup>9</sup> See 6.2 for a discussion of active soil gas sampling techniques.







cording to their physical properties and the residence opportunity presented to them along their migratory path. This process has been described as an in-situ chromatographic-like separation of contaminants (11). Emplacement, or the establishment of contaminant residence, is a highly dynamic process. Contaminants move from one phase to another as changes occur in both chemical and physical equilibria. Important changes impacting phase residence change include temporal variations in moisture content, soil temperature and level of microbial activity.

4.5.1 One interesting example of disruption in equilibrium conditions is the act of sampling soil gas. Many soil gas sampling systems rely on large volume recovery of soil gas to provide a sample that is believed to be representative of the soil atmosphere in situ. Movement of this soil gas by convective flow through unsaturated soils can cause upward changes in vapor phase contaminant concentration at the expense of other phases.

4.5.2 In natural systems, temporal increases in soil moisture cause gradual increases in solute phase emplacement at the expense of other phases. It is unrealistic to attempt to characterize a static soil gas equilibrium in the vadose zone because this equilibrium is never achieved. For this reason, soil gas data sets based on specific contaminant concentrations and generated at different times are usually not comparable for the absolute values generated by each temporal sampling event. Qualitative comparison of data generated by the same soil gas method and performed at different times is permissible. Generation of a single data set by reconnaissance soil gas sampling and subsequent infilling of data to form a single data set is strongly discouraged.

4.5.3 Attempts to compensate for temporal variations in phase equilibria have been attempted by collecting samples that approximate replicates at known locations and adjusting succeeding data up or down to compensate for observed changes. This procedure is also strongly discouraged, because the number of variables affecting observed changes are too great. Moreover, the ability or willingness of most investigators to determine the most significant effects upon phase equilibria is insufficient to be of use.

4.5.4 Data sets generated by different soil gas sampling techniques may not be comparable as a direct result of differences in efficiency of recovery of contaminants from specific phases. Not only can these data sets differ in measured contaminant concentration, but they can vary substantially in composition as well.

4.6 Degradation of contaminants occurs in the vadose zone through oxidation or reduction reactions that can be biogenic or abiogenic in nature. This process can occur both aerobically and anaerobically to mitigate contaminant levels. Degradation is most often recognized in shallow, permeable soils where favorable conditions exist for oxidation of labile compounds, however other vadose environments can be conducive to degradation. Specific environmental conditions are required for degradation processes to occur. For abiogenic degradation, redox potential and soil pH can be rate controlling factors. For biodegradation, necessary environmental conditions include the presence of microorganisms capable of adaptation to the contaminant as substrate, conditions favorable to population increases of these microorganisms and migration pathways for contaminants to

come in contact with these microorganisms. Most soils contain naturally occurring populations of various microorganisms that can degrade petroleum products (12). Contaminant biodegradation is known to occur in groundwater (13) and in soils (14) prior to contaminant partitioning into a vapor phase. Contaminant biodegradation rates for some compounds are highly variable and are controlled by a number of kinetic factors influencing the distribution of microorganisms responsible for degradation. These include aerobic versus anaerobic environments, contaminant type and temperature (15, 16).

4.6.1 Degradation rate can approach, equal or periodically exceed the rate of contaminant emplacement into the vadose zone, such that contaminants are not detectable by soil gas monitoring. This mechanism can result in soil gas data which are not representative of an underlying contaminated condition (17).

4.6.2 Labile contaminants can be degraded to compounds that may or may not be detectable in soil gas. Aerobic degradation can produce carbon dioxide which can be monitored as an indirect indicator of the presence of contaminants (18), or organic acids and phenols (13) that are not routinely detectable in active whole air soil gas samples. In alternative to whole air methods, use of an appropriate adsorption medium may facilitate recovery of such compounds for analysis by desorption and gas chromatography-mass spectroscopy. Anaerobic degradation can produce compounds including methane, ethylene, propylene, acetylene, and vinyl chloride which also can be monitored as an indirect indicator of the presence of contaminants. Caution must be used in attributing elevated levels of these compounds to biodegradation, because competitive processes can confuse the interpretation of absolute concentration values and potential sources.

4.6.3 Biodegradation of contaminants in the vadose zone can proceed naturally by adaptation of indigenous microbial populations to metabolize contaminants as primary substrate, or by introduction of foreign populations which have been preconditioned to metabolize contaminants of interest. Case histories demonstrate the absence of certain compounds in soil gas contaminant suites for which biodegradation has been named as the responsible process (17, 19, 20). Such cases address the attenuation or complete absence of simple aromatic hydrocarbons, some of which are halogenated, in soil gas. This phenomenon may be controlled by the availability of oxygen as has been demonstrated in the laboratory (13). Other compound classes can exhibit similar effects.

4.6.4 Other processes may share responsibility for the actual or apparent absence or attenuation of some contaminants in soil gas sample sets. In some cases where attenuation of contaminant concentration is attributed to degradation, combinations of high soil clay, organic matter and pore water content can reduce the recovery efficiency of certain soil gas sampling techniques for certain contaminants such that contaminant concentrations fall below detection limits. Care must be exercised in attributing a lack of contaminants in soil gas samples to degradation.

4.7 *Summary Procedure for Soil Gas Sampling*—Vadose zone monitoring methods have a set of procedures, both general and specific, that must be consistently followed in







order to provide maximum data quality and usefulness. Soil gas monitoring is no exception, with six primary procedures common to all soil gas monitoring techniques. The procedures are a planning and preparation step including definition of data quality objectives, the act of sampling soil gas in the field, handling and transporting the sample, sample analysis, interpretation of the results of analysis, and preparation of a report of findings.

4.7.1 The planning and preparation step begins with the formulation of project objectives, including purpose of the survey, appropriate application of the data to be collected and data quality objectives.

4.7.2 Data can vary in quality due to sampling methodology, sample preparation, analytical procedures, laboratory quality control, and available documentation. Quality assurance programs include all of the activities necessary to provide measurement data at a requisite precision and bias (see Practice 1357). Quality assurance objectives for soil gas monitoring are similar to those for atmospheric air monitoring. The overall quality assurance objective for measurement data is to ensure that data of known and acceptable quality are provided. In order to meet these objectives, data quality objectives should be defined for data measurements in support of the soil gas data interpretation. These are comparability, completeness, representativeness, bias and precision. The comparability of the data collected refers to the ability to interpret the results in light of previous data collection efforts. Completeness refers to the number of samples collected and analyzed compared to the planned number of samples. Representativeness is a measure of the degree to which analytical results reflect true field conditions. Field contamination and sampling intensity are two factors affecting representativeness. Bias is a generic concept of exactness related to the closeness of agreement between the average of one or more test results and an accepted reference value (see Practice E 177). The precision of a measurement process is a generic concept related to the closeness of agreement between test results obtained under prescribed like conditions from the measurement process being evaluated. Overall precision and bias targets for chemical contaminant measurements can be set at 10 % allowable deviation with 90 % confidence limits. In all of these quality assurance activities one must take into consideration that factors including geophysical conditions and definition of sampling volume in the vadose zone often have higher variability than analytical equipment calibration procedures.

4.7.3 Table 1 provides suggested quantitative limits for data quality objectives.

4.7.4 The planning and preparation step continues with the evaluation of available information already gathered for the project area. These efforts culminate in the selection of an appropriate soil gas monitoring method and a survey design which best fits the project objectives within budgetary constraints. Prior to actual field work, investigators must obtain the necessary permits and landowner permission for property access. When a survey area is pending sale, investigators should obtain written permission to conduct the survey from both the buyer and the seller. Moreover, when a soil gas survey is being performed as a service, no work should proceed on the survey without a fully executed consulting agreement between the investigator and the client

TABLE 1 Suggested Quantitative Limits for Data Quality Objectives

QA/QC Objective	Measure	Formula	Limit
Accuracy Precision	Laboratory standard	Standard recovery	90 to 110 %
	Field replicate	Relative standard deviation	< 20 %
	Laboratory replicate	Relative standard deviation	< 20 %
Representativeness	Air blank	Bias	< 10 %
	Cross contam. blank	Bias	< 10 %
Completeness	Completion (%)	Relative compl.	> 90 %
Comparability	Prof. judgment	NA	NA

for whom the survey is being conducted.

4.7.5 Actual field work consists of recovery of soil gas samples. The method selected should be based upon site specific factors and dictated by the project objectives. A detailed discussion of soil gas sampling methods is provided in 6.1.

4.7.6 As samples are being recovered, they must be handled and transported in such a way as to assure preservation prior to analysis. A detailed discussion of sampling and transport is located in 6.5.

4.7.7 The presence of contaminants is determined through analysis of the soil gas samples. This step is controlled to a large degree by the QA/QC objectives of the survey. A discussion of sample analysis is provided as 6.6.

4.7.8 Data interpretation is largely an iterative process of review of the raw soil gas data out of context, a review of the soil gas data in context of other site characteristics and the formulation of conclusions based upon all known information. A discussion of soil gas data interpretation is located in 6.7.

4.7.9 Finally, a report of findings is generated in a format that is selected to be appropriate to the requirements of the end users. Section 7 provides options that can be addressed in reporting as well as recommendations of topics that should be included in all soil gas summations.

## 5. Significance and Use

5.1 *Application of Soil Gas Monitoring*—Soil gas monitoring is an extremely versatile method in that it can be adapted to conform to the requirements of dissimilar industries for a wide variety of applications. A number of soil gas techniques have been utilized in the agricultural (21), petroleum (22, 23) and minerals (24) industries. Certain applications have been exercised for well over 50 years. Soil gas monitoring has been utilized in research efforts, including the monitoring of underground coal gasification retorts (25). Application to the environmental industry is comparably recent but very effective as a rapid and relatively inexpensive method of detecting volatile contaminants in the vadose zone. Field screening, of which soil gas monitoring is a basic component, has been demonstrated to be effective for selection of suitable and representative samples for other more costly and definitive monitoring methods (26). Soil gas monitoring is useful to assess the extent of ground water contamination for certain contaminants and field environments (27). Soil gas monitoring is also a viable method of monitoring subsurface contaminant discharges from underground storage tanks (28). New applications of the soil gas







monitoring are periodically developed and published in the referenced literature. The method may be useful in the study of unsaturated flow. In most instances, the method can make use of very light-weight, portable and inexpensive tools made from commonly available materials. Soil gas monitoring has become a widely accepted method for locating subsequent environmental monitoring and remediation activities such as ground water monitoring wells, contaminant product recovery wells or excavations to recover contaminated soil. Soil gas monitoring has made a significant contribution to ground water monitoring and remedial planning on sites that fall under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (29). This method is highly useful at the initiation of Phase II environmental assessment action in determining the presence of volatile organic contamination of real property in a pending sale.

5.1.1 In any application, soil gas monitoring can be performed over a wide range of both spatial and temporal designs. Spatial designs include soil gas sampling in profiles or grid patterns at a single depth or multiple depths. Multiple depth sampling is particularly useful for contaminant determinations in cases with complex soil type distribution and multiple sources. Depth profiling can also be useful in the determination of the most appropriate depth(s) at which to monitor soil gas, as well as the demonstration of migration and degradation processes in the vadose zone. Temporal designs include the long-term monitoring of the vadose zone for the appearance of volatile organic contaminants from known potential sources such as underground storage tanks and solid waste landfills. Temporal designs are especially useful in monitoring the effectiveness of contaminant remediation efforts.

5.1.2 Soil gas monitoring in the vadose zone is an ideal reconnaissance tool and screening technique in most applications. However, site specific and contaminant specific limitations can cause this technique to be unsuccessful in meeting project objectives. Caveats exist in all soil gas monitoring procedures that can frustrate efforts to successfully apply the method to any application.

5.2 *Limitations*—The most significant limitation on soil gas monitoring is the inability to utilize the method as a stand alone technique. Soil gas monitoring does not provide repeatable quantitative information over time due primarily to the dynamic nature of phase equilibria in the vadose zone and secondarily to unavoidable inconsistencies in sampling practice. As a result of geologic variability in the vadose zone and the multitude of unique sampling devices currently being used in the field, quality assurance and quality control protocol, discussed in 6.4, cannot provide the rigor required as in a test method. For these reasons, soil gas data in itself cannot be used to provide definitive answers about the location or absence of buried contaminants. Moreover, the success of any soil gas monitoring method is strongly dependent upon effects related to geologic variation and moisture content in the sampling horizon as well as the physical properties of the target contaminants.

5.2.1 False negative results can occur as a direct result of the incompatibility of a specific procedure with the properties of the sampling horizon or the target contaminants, or both. Soil gas data cannot be used to establish bulk volume

or the commerciality of buried petroleum, natural gas, or ore bodies.

5.2.2 With the necessary analytical procedures, soil gas can be examined for compositional anomalies, a very useful technique for multiple source problems. In some instances, contaminant occurrences are limited to single species (compounds, mercury, etc.), however more often than not the contaminant source is a mixture of organic chemicals that have a unique chemical compositional character consisting of both normally evaluated priority pollutants and non-priority pollutant chemicals that may be overlooked. By identifying and using compositional information, many problematic site situations such as degradation can be minimized by targeting the more refractory compounds associated with the contaminant occurrence. This interpretive method is impossible to model for an industry wide application due to variation in methods and technique.

5.2.3 A basic limitation of the technique is that due to the ease of procurement and use of soil gas sampling devices, there is a tendency for inexperienced personnel to oversimplify any and all aspects of the method. Investigators must consider the experience level and technical ability of personnel who acquire soil gas samples and attempt to interpret the results. Certain procedural facets are not trivial, as discussed in Section 6. The results of certain techniques tend to be affected by minor variations in procedure despite apparent adherence to a "Standard Operating Procedure."

5.2.4 Atmospheric air contamination is not a trivial problem corrected by simple device-oriented field practice. Many sampling systems recover very large volumes of "soil gas" that may actually represent a mixture of soil gas and atmospheric air. This mixing occurs through the introduction of ambient air adjacent to the sampling device and through macroporous pathways in the soil which are far from the sampling device. Some environmental investigators avoid the impact of this problem by reasoning that contaminant quantities in the soil are so great that they are detected despite atmospheric mixing. For qualitative approaches with non-rigorous quality assurance/quality control (QA/QC) objectives this mixing problem can be insignificant. For detection of compounds that exhibit only marginal partitioning preference for the free vapor phase, the mixing problem can be a fatal flaw in procedure. Moreover, contaminant concentration and composition investigations can be rendered useless by variations in the magnitude of mixing at various sample locations and depths in a survey area.

5.3 *Comments on Limitations of Soil Gas Monitoring*—Many investigators believe that soil gas monitoring is not an effective vadose zone monitoring method for certain volatile organic applications, in certain geographic regions or during certain seasons of the year, or both. The applicability of soil gas monitoring is controlled by physical and chemical properties and processes in the subsurface and not by factors that are obvious at or above the surface. For example, one common misconception is that soil gas monitoring is not effective during the winter season. The impacts upon soil gas measurement of elevated soil pore water content, reduced vadose zone temperature and the presence of frost, typical of numerous regions in winter, are obvious for many facets of most soil gas monitoring methods. Modification of standard operating procedure, such as an increase in sampling depth,







or selection of another soil gas monitoring method altogether can minimize the negative impacts of seasonal field conditions. It is important to understand that the responsibility for success or failure in soil gas monitoring can reside as much in the planning phase of a survey, including the method chosen, as in factors controlling the chemical and physical processes at work in the subsurface. Even with apparently ideal field conditions and with a carefully planned survey, soil gas monitoring can succeed or fail due to unknown factors controlling contaminant migration and emplacement. Soil gas monitoring is no different than any other measurement method, in that investigators must maximize effort in planning and implementation of procedure to maximize the likelihood of success.

## 6. Approach

**6.1 Sampling Methodology**—Soil gas sampling methodology has evolved over time and through practice in several industries. The equipment with which to perform this monitoring technique is highly varied, although it may be categorized into basic types (see 6.2.2). The literature provides numerous discussions about the design of some of this equipment (10, 30, 31, 32, 33). The selection of a soil gas sampling method involves consideration of three primary issues. These are the type of sampling system, the methodology of application of that sampling system and the rigor of the field QA/QC protocol. Each of these issues is discussed in this guide, however, no single method or procedure is recommended to the reader due to the variation in site specific factors. As many as one hundred unique soil gas sampling systems exist that arise from variations or combinations, or both, of the many facets described in this guide. Some systems are highly versatile for numerous applications. Others are functional for more limited or specific applications. Informed investigators must assume the responsibility of selecting the technique most appropriate to the subject application, whether that technique is commercially available from contractors or equipment suppliers, or reliant upon the ingenuity of the investigator in the field utilizing commonly available materials. Success in choosing an appropriate sampling device or an entire sampling system is dependent upon the investigator's level of understanding of vadose zone processes, contaminant properties and appropriate applicability of the soil gas method.

**6.1.1** The application of any of these methods must be controlled by strict adherence to a standard operating procedure. Occasional deviations as dictated by unusual field conditions should be recorded in the project field notebook. Inadvertent minor deviations in field procedure can result in misinterpretation of the data acquired.

**6.2 Sampling Systems**—Six basic sampling systems exist. These are based upon the collection of soil gas by a whole-air or sorbent method in an active or passive approach, or upon the principle of collection of a soil or water sample for subsequent sampling of a contained headspace atmosphere. Contained atmosphere methods do not yield samples representative of in situ vadose zone atmospheres.

**6.2.1 Whole-air methods** sample the soil atmosphere as a mixture of gases, including contaminant and non-contaminant vapors. Sorbent methods sample contaminants adsorbed onto a collection medium exposed to a whole-air

sample stream. Active methods are those that obtain a soil gas sample by positioning a sampling device in the subsurface and the withdrawal of soil atmosphere through the device from the sampling horizon. Passive methods are those that obtain a soil gas sample by placing a collection device in the soil or on the soil surface, and allowing the atmosphere within the device to come into compositional equilibrium with the soil atmosphere. Four of the six basic sampling systems arise from these approaches, namely the whole air-active approach, the sorbed contaminants-active approach, the whole air-passive approach, and the sorbed contaminants-passive approach. Two additional systems exist that are based respectively upon the collection of a soil or water sample for subsequent sampling of a small volume headspace atmosphere.

**6.2.2 Whole Air-Active Approach**—This method of soil gas sample collection involves the forced movement of bulk soil atmosphere from the sampling horizon to a collection or contaminant device through a probe or other similar apparatus (10, 34). Contained samples of soil atmosphere are then transported to a laboratory for analysis, or the sampling device is directly coupled to an analytical system. Whole air-active sampling is best suited to soil gas monitoring efforts where contaminant concentrations are expected to be high and the vadose zone is highly permeable to vapor. Probes exist that must utilize pre-existing holes or that can penetrate the vadose zone by driven means. These devices can be very simple and light-weight for low cost mobilization (35), or they can be affixed to vehicle mounted drills or hammers useful for larger, more complex surveys at a higher cost of mobilization. The whole air-active technique can be combined with other monitoring methods such as soil monitoring for engineering purposes (36) in some survey environments. The success of this practice can be highly site-specific.

**6.2.2.1 Ground probes** can be of small to large internal volume. The development of sampling devices with smaller internal volumes equating to smaller purge volumes is a significant improvement, providing samples which are more representative of soil atmosphere, and a greater ease of equipment decontamination between usages. Sample size can vary from a few millilitres to many tens of litres depending upon the sample rate through the probe, the vapor storage capacity of the soil and the ability of the soil to deliver vapor to a probe under vacuum.

**6.2.2.2** The success of the active approach is strongly dependent upon soil clay, organic matter and moisture content. Driven probes tend to destroy natural soil permeability around the body of the probe due to soil compaction concurrent with insertion. This can be a severe limitation in moist, heavy clay soils. In very dry, cemented soils, driven probes can create radial fractures that can enhance soil permeability to vapor concurrent with insertion. These fractures can communicate atmospheric air with soil atmosphere, a limiting factor for obtaining representative, large-volume soil gas samples. The effect can be so severe as to lower recovered contaminant concentrations in the soil gas sample below the limits of analytical detection. This is especially true for highly sorptive or water soluble compounds, or both. Some investigators have attributed the poor







recoveries of these compounds exclusively to other processes, that is, degradation (21, 37).

6.2.2.3 Methods requiring a pre-existing hole for probe insertion (38) made with a commercially available "slam bar" can provide supportable contaminant data where contaminant concentrations and soil permeability to vapor are high, however the act of making a hole with a "slam bar" and subsequent removal of the "slam bar" can encourage soil contaminant venting and lower sample representativeness. Insertion of the sampling probe into this hole further degrades representativeness by additional venting of contaminants as the probe displaces the atmosphere in the hole upon insertion. Purging of the probe prior to sampling under conditions of low soil permeability and low contaminant concentration may lower contaminant levels below the limits of analytical detection. Methods requiring a pre-existing hole for probe insertion are not recommended for soil gas sampling from soils with high clay and moisture contents.

6.2.2.4 Excellent discussions of numerous whole air-active sampling systems may be found in the literature (10, 21, 37, 39). Investigators must consider the caveats and limitations of the whole air-active approach when selecting a certain method for a specific application.

6.2.3 *Sorbed Contaminants-Active Approach*—The sorbed contaminants-active method of soil gas sample collection also involves the forced movement of bulk soil atmosphere from the sampling horizon through a probe or other similar apparatus, but to a collection device designed to extract and trap sample stream contaminants by adsorption (40, 41). This system is well suited to sites where the soil may be highly permeable to vapor and where the contaminant concentration may be lower than required for successful whole-air surveys. Sorbent devices are designed to concentrate the components of interest and remove some of the soil gas components known to interfere with sample analysis.

6.2.3.1 Contaminant trapping is accomplished by use of an adsorbent collection medium such as charcoal or a carbonized molecular sieve adsorbent (43, 44), as well as porous polymers, silica gel and activated alumina (10). This approach is especially amenable to the detection of nonpolar volatile organic compounds. Organic compounds that are reactive, oxygenated or are gaseous at room temperature are either not adsorbed by or are not efficiently desorbed (42) from charcoal. Sorbent collection devices are commercially available or can be specially prepared with an appropriate sorbent material that concentrates desired compounds for future analysis. Colorimetric detector tubes are available which will provide an indication of the presence of target compounds at the time of sampling. These devices are limited in application by the high concentration requirements for many compounds and the compound-specific nature of these tubes.

6.2.3.2 The effectiveness of the sorbed contaminants-active approach can be limited by high vadose zone clay and water content, reducing the ability of the soil to transmit vapor through the sorbent trap. Commercially available sorbent traps come with information suggesting maximum, minimum and optimum sampling rate through the trap. Soil characteristics can limit flow rate to a point below the minimum recommended rate, affecting the performance of the trap and the reproducibility of adjacent samples. Interac-

tion of the sorption media with target compounds during desorption in the laboratory can form artifacts, restricting the interpretive value of the data. Some sorption media are prone to irreversible adsorption (see Definitions D 2652). Some may be affected by high soil gas relative humidity. Humidity greater than 60 % (very common for soil gas) can reduce the adsorptive capacity of activated charcoal to 50 % for some chemicals. Presence of condensed water in the sample tube will indicate a suspect sample (see Practice D 3686). Anticipation of these problems is recommended for all sorbent techniques, and a thorough quality control plan should be designed and implemented as is discussed in 6.4 of this guide.

6.2.3.3 Special sample preparation is required for samples adsorbed onto a trapping medium. This preparation step consists of the thermal or solvent desorption of the contaminants from the trapping medium. Proper practice will promote needed accuracy and precision in the determination of contaminant concentrations above specified values (see Practice D 3687).

6.2.4 *Whole Air-Passive Approach*—This method of soil gas sample collection involves the entry of bulk soil atmosphere or soil atmosphere components from a near-surface sampling horizon to a collection or containment device through a flux chamber or other similar apparatus (30). Enclosure devices sample vaporous emissions from a known soil surface area capped by a chamber. The volume of the chamber is continuously swept by injection of a gas of known composition, and the resultant carrier gas-contaminant mixture is collected for analysis. The rate of emission or "flux" of contaminants can be calculated if flow rate of injected gas and contaminant concentration in the sample are determined.

6.2.4.1 The whole air-passive approach is useful to some very specific applications. This method may be used, for example, to monitor contaminant emissions from soil or water to assess the health hazard risk of such emissions to the general public. Determination of the extent of contamination by volatile organic compounds has been performed with whole air-passive devices, however the application of other types of systems is far more common.

6.2.4.2 A key to successful operation of a whole air-passive system is that the system is able to recover volatile compounds as they are emitted from the vadose zone. The effects of changes in barometric pressure, soil temperature and soil moisture content are not quantifiable from site to site due to site specific variables controlling vapor phase contaminant migration and the rate of contaminant partitioning into the vapor phase. The presence of contaminants or naturally occurring organic matter floating on surface water may impact the rate of entry of certain vapor phase contaminants into the chamber.

6.2.4.3 The whole air-passive method is limited in application primarily due to the great degree of dilution of contaminants in the sample stream by injected gas. This can decrease method sensitivity by lowering contaminant concentrations to levels below the detection limits of the analysis method chosen. Further decrease in method sensitivity results from the fact that soil gas contaminant concentrations are generally lower at the surface than even at nominal depths. Soil characteristics such as high water saturation, soil







cements, clay content and organic matter content will negatively impact results of these systems by restricting the rate of contaminant flux to the chamber.

6.2.4.4 Additional limitations exist. Certain devices limit flux rates into the chamber due to aspects of design. Soil macroporosity such as desiccation cracks extending beyond the collecting device will vent soil vapors to the atmosphere that will not be collected by flux chambers unless monitoring locations are biased to include these features.

6.2.5 *Sorbed Contaminants-Passive Approach*—This method of soil gas sample collection involves the passive movement of contaminants in soil to a sorbent collection device over time. Passive samplers that have been applied to sampling soil gases of environmental concern include occupational health volatile organic compound monitors (44) and a sampler originally developed for detecting the presence of hydrocarbons in petroleum exploration (33, 46). Both devices use charcoal as a sorbent; the former as a flat film and the latter coated on a wire. Passive samplers are housed in containers up to several inches in diameter, depending upon the design. They are placed open end down in holes that are usually less than 5 ft (1.5 m) deep, that are then backfilled (32). These monitors are generally left in place from two to ten days, although certain passive collectors can be left in place for a period of 30 days or more for certain applications. For at least one device, exposure efficiency can be determined.

6.2.5.1 The sorbed contaminants-passive approach can be employed in a wide range of geological conditions. Frozen ground and high water saturation may not limit the ability of the monitors to collect contaminants (46), although the composition of the contaminant suite may be impacted by related alterations in partitioning equilibria.

6.2.5.2 The sorbed contaminants-passive approach depends upon the ability of contaminants to move through the vadose zone to the passive collection device. Numerous adsorption media can be used to collect contaminants (see 6.2.4). The principle of passive-sorbent monitors relies on adsorbent reduction of the equilibrium concentration of contaminants around the monitor over time, therefore creating a concentration sink, that is, a continuous state of disequilibrium, in the vicinity of the monitor. This can encourage continued migration of contaminants toward the monitor when conditions for contaminant partitioning into the vapor phase are favorable. Migration of contaminants in the vadose zone toward a passive-sorbent device is strongly controlled by vadose zone character and the chemical and physical properties of the subject contaminants. Contaminants may move from a few feet to thousands of feet, or not at all.

6.2.5.3 Many investigators attribute the principle mechanism of contaminant migration to a passive-sorbent device to diffusion, that is, the movement of organic vapor or gas molecules from a region of high concentration to a region of low concentration as described by Fick's law (see Practice D 4597). Fick's law of diffusion states that for a constant concentration gradient, the mass of material transferred to the sampling layer can be expressed as:

$$M = \{DA(C - C_o)t\}/L \quad (5)$$

where:

$M$  = mass of the material, ng,

$D$  = diffusion coefficient,  $\text{cm}^2/\text{min}$ ,

$A$  = cross sectional area of diffusion cavities,  $\text{cm}^2$ ,

$L$  = length of diffusion path, cm,

$C$  = concentration at face of sampler,  $\text{ng}/\text{cm}^3$ ,

$C_o$  = concentration at adsorbing layer surface,  $\text{ng}/\text{cm}^3$ , and

$t$  = exposure time, min.

6.2.5.4 The cross sectional area of a diffusion cavity, the length of the diffusion path and the quantity  $(C - C_o)$  are impossible to accurately measure for soil gas contaminants interacting with a passive-sorbent sampler. There is some debate as to whether passive samplers measure flux or total contaminant concentration (32) in the vicinity of the trap. Due to the fact that the mass of the material transferred to the sampler by diffusion, a key measurement, cannot be determined, the debate will no doubt continue. It is reasonable to assume that a combination of processes is responsible for contaminant migration to sorbent traps, including diffusion, dispersion and mass transfer. All migration processes are impacted by partitioning equilibria.

6.2.5.5 Ambient air represents an atmospheric contaminant concentration sink that encourages a strong vertical vector of contaminant migration. This prevailing upward movement of contaminants from sources at depth results in contaminant concentration gradients throughout the vadose zone. The sorbed contaminants-passive method makes use of this contaminant flux (see 6.2.4) to collect long-term, nondisruptive samples of volatile contaminants. The method can collect contaminants which are compositionally representative of the contaminant mixture favoring the vapor phase. The quantity of volatile organic compounds trapped by these devices is proportional to the concentration gradients of contaminants present near the collection device and the affinity of the contaminant(s) for the collection medium.

6.2.5.6 As with active sampling protocols, specific issues exist affecting the function and calibration of passive monitors. Soil gas, even in the drier climates, will be at a relatively high humidity condition. This humidity can affect the collection efficiency of the adsorbent media. In soils of low permeability, contaminants commonly move very slowly. This can create a condition of near-zero contaminant concentration in the soils immediately adjacent to the monitor if the sorptive potential of the monitor is higher than that of the soil. When soil contaminant concentrations are rapidly depleted, that is, as the result of invasion of the sampling horizon by meteoric water, the passive monitor can source contaminants back to the soil.

6.2.5.7 The sorbed contaminant-passive approach to soil gas monitoring is not immune to the migration, emplacement and degradation factors affecting all soil gas monitoring techniques. It is not possible to measure the efficiency of passive-sorbent monitoring devices because the bulk volume of soil gas affected by the sorbent trap cannot be measured. Care must be taken not to contaminate the sorbent samples during installation or by backfilling with contaminated soil. Such care is comparable to potential problems for any measurement method in which a contaminated layer is penetrated.

6.2.6 *Soil Sampling for Subsequent Headspace Atmosphere or Extraction Sampling*—This method examines contaminants that are present in a headspace atmosphere







above a contained soil sample. Note well that this headspace atmosphere is not true soil gas (see 3.1.11), but is an artificial atmosphere formed above a potential contaminant source, that is, the soil sample. Contained atmosphere methods do not yield samples representative of in situ vadose zone atmospheres. Headspace atmospheres differ from in situ vadose zone atmospheres in that large percentages of vapor phase and moderate percentages of solute and sorbed phase contaminants can be lost in the act of soil sampling. This method is not generally recommended for a broad spectrum of cases due to numerous limitations and caveats. In comparison to other methods described in this guide, soil sampling for subsequent headspace atmosphere or extraction sampling can be a relatively poor method for determining many of the more volatile contaminants. Headspace atmospheres contain residual sorbed and solute phase contaminants that have partitioned to the vapor phase in the contained environment; most headspace approaches are reasonably efficient in recovery of some fraction of sorbed and solute phase contaminants. Contaminants in these phases in situ are recovered from a headspace after they have partitioned into the vapor phase. Recovery efficiency of contaminants in the vapor phase in situ ranges from moderate to poor.

6.2.6.1 Important criteria exist to consider when selecting a device that will provide suitable samples (see Guide D 4700). The equipment required is simple and readily available. Some commonly used augers are not suitable for soil sampling in support of subsequent headspace atmosphere sampling due to soil disturbance. Depths of auger investigations are limited by ground water conditions, soil characteristics and the equipment used (see Practice D 1452). Suitable procedures for some methods are described in the literature (47, 48). Current soil preservation practice may not apply (see Practice D 4220).

6.2.6.2 Limitations and special procedures exist for the application of soil sampling for subsequent headspace gas analysis. Filling head space with solvent can support a subsequent solvent extraction procedure. Some investigators minimize the effects of devolatilization by rapidly recovering small soil core plugs with polypropylene syringes which have been modified to accommodate recovery of soil plugs. Investigators also attempt to maximize partitioning of contaminants into the vapor phase by adding buffering solutions or sodium sulphate and phosphoric acid to the vial prior to sealing, in order to shift the activity coefficients of the subject contaminants to favor the vapor phase. Aqueous suspensions of solvent slurries of soil can be ineffective for the determination of high molecular weight labile compounds. Their persistence in soil is the result of physical entrapment in soil microporosity (49). Recovery efficiency of contaminants in soil headspace can be greatly enhanced by pulverization of the soil (50) in a ball mill or other similar apparatus. The method is biased toward recovery of contaminants in the sorbed, solute and occluded phases in situ due to the loss of pore space gas in preference to contaminants adsorbed onto the soil particles or trapped in soil micropores. Contaminant degradation, especially biodegradation, in the container is encouraged by the creation of an aerobic, moist environment during sample handling and transport prior to analysis. However, a simple method to minimize the effects of

biodegradation can be achieved by storing samples, when necessary, at approximately 4°C in the dark.

6.2.6.3 Acid extraction of volatile organic compounds is widely used in geochemical exploration for petroleum and natural gas. Soil samples are placed in a closed vessel, heated and evacuated to remove vapor phase contaminants. The addition of acid to the evacuated chamber causes release of hydrocarbons believed to be bound to the soils by carbonates (22). Hydrocarbons are determined by analysis of resulting vessel atmospheres. Refinements to this method have been developed (48), however the method is designed not to determine compounds in the vapor, sorbed, or solute phases. Method sensitivity is therefore greatly reduced.

6.2.7 *Soil Pore Liquid Headspace Gas Approach*—In the vadose zone, soil gas monitoring can be accomplished in combination with soil pore liquid sampling through the use of a suction lysimeter, a pan lysimeter or a free drainage glass block sampler. The suction lysimeter installed in the vadose zone is most commonly employed for this purpose. Temporally designed surveys are ideally suited to this method.

6.2.7.1 After a lysimeter has been installed for some period of time, initial aliquots of vapor sampled from a soil pore liquid sampler will be in compositional equilibrium with solute phase contaminants when pore liquid tensions are within the operating range of the lysimeter and if pore sizes are not so great as to cause loss of hydraulic contact between the soil and the porous segment of the lysimeter. Subsequent aliquots of soil gas may compositionally resemble soil vapor in situ if soil atmosphere enters the porous segment of the sampling device. When the lysimeter cannot recover a pore liquid sample, the soil gas recovered will be compositionally similar to soil vapor in situ.

6.2.7.2 The most common effort to recover soil gas from a suction lysimeter occurs when polytetrafluoroethylene (PTFE) porous segments are employed in sampling environments with high soil moisture tensions (low moisture contents). At tensions above 60 to 80 centibars, soil pore liquid samples cannot be collected (see Guide D 4696). However, soil gas can be recovered through the porous segment and collected at the surface. This alternative sampling effort can monitor soil vapor contaminants utilizing an otherwise unsuccessful procedure until soil moisture contents increase or until an alternative soil pore liquid sampler can be installed.

6.2.7.3 This technique is limited by the relative expense and complexity of installation of the sampling devices as a primary soil gas sampling method. The completeness criterion for quality assurance is difficult to satisfy due to the inability to anticipate the performance of the soil pore liquid sampler with respect to vapor recovery. Moreover, compositional bias toward solute phase contaminants and contaminants volatilized from free product is likely in soil gas samples recovered concurrently with soil pore liquid samples.

6.3 *Methodology in Application of a Sampling Technique*—The likelihood of success of the soil gas sampling technique selected is controlled in part by the methodology in application of that sampling technique. This methodology should be guided by the objectives of the subject project and the perceived spatial and temporal array of the potential sampling targets.







**6.3.1 Grids**—Many problems suitable for soil gas monitoring are best solved by obtaining data distributed over a geographic area. Sampling in grid patterns of variable design and spacing can be a very effective way to provide data coverage over a large area for a very low cost of acquisition. Common applications of soil gas grid sampling are environmental contaminant assessments, exploration for natural resources and the siting of locations for other monitoring or exploratory techniques. Compositional analyses in conjunction with properly designed grid systems are often fundamental to successful evaluation of soil gas monitoring.

**6.3.1.1 Grid spacing** provides for the location of soil gas samples in grid cells. The selection of grid cell size is strongly dependent upon the relationship between project confidence level requirements and cost budget. Small survey targets and complex vadose zone geology require decreased spacing between soil gas sample locations for grid methodology to be successful. Some applications, for example, defining the boundaries of contaminated soil or ground-water contaminant plumes, may require the grid cell area to be as small as 100 to 400 ft<sup>2</sup> (9 to 37 m<sup>2</sup>). Most applications to natural resource exploration monitor naturally occurring volatile compounds in soil atmospheres, requiring closely spaced grids to increase the signal to noise ratio. However, a closely spaced exploratory grid equates to a broadly spaced grid for environmental application in most situations. Common petroleum exploration grid spacing utilizes a grid cell area of approximately 250 000 ft<sup>2</sup> (23 000 m<sup>2</sup>), however grid cells can range from 10 000 to 1 000 000 ft<sup>2</sup> (9 to 90 000 m<sup>2</sup>) depending upon perceived reservoir target area. Widely spaced grid sample arrays are useful in reconnaissance applications such as the establishment of contaminant baselines or evaluation of the exploration potential of a geologic basin. Grid cells for such purposes can be as large as a square mile or more.

**6.3.1.2** The tendency exists for investigators with constrained budgets to utilize overly large grid cell spacings. This action normally results in inadequate, over-interpreted data supporting meaningless conclusions. Care must be taken to avoid this caveat.

**6.3.1.3 Grid arrays** can be designed as regularly spaced and predetermined locations for soil gas sampling or they can be irregularly spaced and continually field modified. Predetermined and widely spaced grid patterns are most useful for reconnaissance work, while closely spaced, irregularly situated or field modified soil gas grid sample sites, or both, are commonly used when targeting contaminant plume boundaries, contamination from underground storage tanks or other detail work.

**6.3.1.4 Multiple depth sampling**, discussed in 6.3.3, when coupled with a soil gas grid sampling methodology, can provide useful data in complex geologic settings and sites with multiple contaminant sources. Computer mapping of closely spaced three-dimensional soil gas grids can provide the investigator with horizontal or vertical cross sections through the subject site, making difficult observations possible.

**6.3.2 Profiling**—Profiling is a soil gas sampling methodology useful to test a linear array for the existence of contaminants. Profiling is most often performed by sampling at closely spaced intervals in a linear array and is displayed as

contaminant concentration or composition versus distance sampled on an  $X - Y$  plot. Concentration data are often displayed logarithmically on the ordinate ( $Y$ ) axis, while single components or ratios of compositional data are often displayed linearly on the ordinate axis.

**6.3.2.1** For environmental applications such as leak detection along the length of a pipeline or monitoring of contaminant encroachment across a property boundary, soil gas samples are recovered along a profile at intervals from 25 to 100 ft (8 to 30 m) (23). Profiling for natural resource exploration can be performed at sample intervals from 50 to 500 ft (15 to 50 m), depending upon the application.

**6.3.2.2** Profiling is useful as a corroborative tool for other monitoring or exploration methods. For example, a soil gas sample profile acquired coincident with a seismic profile can suggest primary contaminant migration pathways or the boundaries of confining layers in shallow, complex geologic settings. This technique has been demonstrated as highly effective in reducing exploratory risk prior to drilling for petroleum and natural gas, by suggesting the presence of hydrocarbon seepage coincident with structures with reservoir potential defined by the seismic method (51).

**6.3.2.3** Soil gas profiling is also a convenient methodology effective in comparative evaluation of multiple soil gas sampling techniques. Due to variations common to the dynamic equilibrium conditions over small spatial and temporal intervals in the vadose zone (see 4.1), comparisons of multiple soil gas techniques using only one or a few soil gas samples recovered from nearly identical locations will not result in a valid comparison. However, a visual overlay of soil gas profiles resulting from the implementation of the various sampling techniques can provide a rapid and definitive comparison as to the efficiency of recovery of subject contaminants by a particular sampling system in a specific sampling environment. Similarly, comparison of profiles obtained by using the same soil gas sampling system can provide a direct measurement of system accuracy for quality control purposes.

**6.3.2.4** Some investigators compare geographically coincident profiles obtained with the same sampling system at times differing by days or even years in order to generate a data correction factor in order to enhance data comparability. This practice is strongly discouraged. Factors not anticipated in this practice such as the effects of the dynamic equilibrium in the vadose zone, unavoidable changes in procedure due to personnel substitutions, contaminant movement or cultural influence on the sampling environment can have impact on results that are far more significant than the apparent correction.

**6.3.3 Multiple Depth Sampling**—Methodologies encompassing multiple depth sampling normally have one of two goals, that is, to monitor changes in soil gas contaminant fractions versus depth, and to closely follow a single sampling horizon for an entire soil gas grid or profile.

**6.3.3.1** When the goal of a survey is to monitor contaminants over varying depths, some sampling systems can recover soil gas samples as probes are advanced deeper into the vadose zone. This practice is helpful in determining the optimum sampling depth for a particular site or to demonstrate the presence or absence of soil atmosphere contamination in a certain horizon. Soil gas contaminant concentrations often increase with depth as the sampling horizon







approaches contaminated ground water or other source of soil gas contaminants (52). Caution must be exercised when soil gas sampling tools are advanced to increasing depths due to the fact that cross contamination of some or all of the sampling system is unavoidable. This situation limits quality control for this type of multiple depth sampling. Attempts to eliminate cross contamination in multiple depth sampling by replacement or decontamination of sampling equipment with each new sample aliquot also result in limited quality control. Tool withdrawal and tool reinsertion result in venting of the sampling environment via an open hole. The open hole behaves as a macroporous pore space, allowing enhanced partitioning into the vapor phase and convective migration to the atmosphere. The end result is a reduction in representativeness for each subsequently recovered soil gas sample.

6.3.3.2 Multiple depth sampling can also be used to focus a sampling program into a single geologic unit or suite of units without regard to depth. This practice is helpful at sites with complex lithologic changes in the vadose zone. Samples can be recovered from lithologies with greater permeability to vapor or greater storage capacity for vapor when bias in sampling depth is necessary to accomplish project goals. This practice involves greater effort and expense than most methodologies due to the necessity to establish the presence, thickness and depth of the target horizons prior to soil gas sampling. The most common application of this methodology is the sampling of soil gas at the top of the capillary fringe.

6.3.4 *Time Variant Methodologies*—Monitoring soil gas in the vadose zone over time can suggest process rates of contaminant partitioning, emplacement, migration and degradation. Practical application of this methodology includes the monitoring of the effectiveness of remedial air-injection systems, the appearance of contaminants sourced from underground storage tanks, the encroachment of contamination onto a subject property from an abutting property and the mitigation of soil and ground-water contamination by microorganisms.

6.3.4.1 Some investigators and regulators with responsibilities at more than one location delegate seemingly simple time variant soil gas monitoring tasks to local personnel. Numerous problems with time variant monitoring can arise in the field as the result of poor system maintenance and record keeping by inexperienced or unmotivated personnel (property owners or parties responsible for contamination).

6.3.4.2 Certain maintenance problems are easily corrected, that is, cleaning bacteria and other foreign matter from detectors or replacing damaged components. Other maintenance problems can be fatal flaws in the methodology. These are principally related to ice formation in the sampling system and destruction of system integrity due to soil frost heaving.

6.3.5 *Combination of Soil Gas Monitoring With Other Vadose Zone Monitoring Techniques*—Soil gas monitoring is not a stand-alone technique. Corroborative support of this reconnaissance and screening tool by other vadose zone monitoring techniques is strongly encouraged. The possible combinations of the various vadose zone techniques with soil gas surveys are numerous. Soil gas can commonly be used as a reconnaissance tool to locate other monitoring devices

such as lysimeters, neutron probes or ground water monitoring/sampling wells. Limits upon such combinations are controlled by budgetary constraints and the investigator's imagination.

6.4 *Field QA/QC*—Quality assurance and quality control procedures (QA/QC) are essential to establishing support for any interpretation of measurement data. Soil gas monitoring data requires a thorough QA/QC protocol confirming that data have been generated to satisfy the data quality objectives for the survey. This requirement is well known, however few investigators subject their soil gas data sets to the rigors of such protocol. Conclusions based upon data of unknown quality may be without merit. Justification for interpretations based upon data of unknown quality is not possible.

6.4.1 QA/QC requirements are dependent upon the data quality objectives defined in the planning phase of the survey. For example, simple contaminant audits require a less demanding QA/QC protocol than contaminant source identification. The goals of the QA/QC effort must be understood by field personnel to assure effective implementation of field QA/QC. A document control officer who is a member of the field team can provide this assurance.

6.4.2 Persons collecting descriptive data should not be varied during a soil gas survey. Soil descriptions, for example, can be somewhat subjective when estimations are made as to soil moisture or clay content. Changes in field personnel can translate into apparent changes in soil lithology that are merely functions of this subjectivity. The document control officer can review field records to discover any obvious errors related to descriptive data.

6.4.3 The results of a soil gas survey are highly sensitive to procedure. Field personnel should closely follow a standard operating procedure. This procedure should include the method(s) selected for the survey including the sampling system, means of sample collection, handling and transport of samples and field based equipment decontamination. A standard practice for equipment decontamination is essential to maximize the integrity of samples that may undergo chemical analyses (see Practice D 5088). Any deviations in the standard operating procedure should be recorded by the document control officer in a field notebook, with notes outlining the justification for the deviation. Data comparability can be severely compromised by deviations from the standard operating procedure.

6.4.4 Field based equipment decontamination can have impact on data quality. This results from the potential for cross contamination of samples due to poorly controlled field cleaning procedure or difficulties presented by the inconvenience of field decontamination. Field based equipment decontamination should not be considered a method of choice, but if unavoidable, must be performed with the data quality objectives for the survey as driving forces for procedure.

6.4.5 Bias of soil gas data describes a situation of consistently lower-than-actual or higher-than-actual soil gas contaminant concentration measurements (32). The bias of a measurement process is a generic concept related to consistent or systematic difference between a set of test results from the process and an accepted reference value of the property being measured (see Practice E 177). Bias can be imparted to







the data through sample site selection, that is, exposure of a sampling device to an environment of enhanced contaminant concentration due to a preferential contaminant migration pathway, or exposure of a sampling device to an environment devoid of contaminants due to barriers to contaminant migration. Bias may also result from malfunction of the sampling system, contaminant degradation or numerous other factors. False positive or false negative values can result, lowering the value of the soil gas data set.

6.4.6 Table 2 summarizes some common problems in soil gas monitoring that can result in biased results.

6.4.7 A sampling program must be conducted during the survey to support evaluation of both the sampling system in the field and the analytical system employed. These samples are known as QA/QC samples. The type and magnitude of QA/QC sampling depends upon the purpose of the soil gas survey and the requirements for data quality attendant to it. It is the responsibility of the investigator to determine the appropriate rigor of field QA/QC protocol. The variation in QA/QC protocol from survey to survey is controlled by the purpose and magnitude of the survey, and can vary to a great degree.

6.4.8 The types of field QA/QC samples are field blanks, travel blanks, sample container blanks, sample probe blanks and sample replicates. Other types of QA/QC samples are analytical in nature and are discussed in 6.6.

6.4.9 Field blanks are samples of ambient air or nitrogen recovered from the sampling system which are recovered to determine contamination of samples by ambient atmospheric air, or, to act as system blanks to test for contamination of the sampling system. Field blanks are used to provide an indication of the probability of leakage in the sampling system or the breakthrough of atmospheric air to the sampling device through macroporous migration pathways in the vadose zone such as soil cracks or moldic porosity. If nitrogen is employed instead of atmospheric air, field blanks can have higher contaminant levels than soil gas. This is especially true for petroleum hydrocarbons in urban environments. At least one field blank should be recovered for each ten soil gas samples, or at least one field blank per sample batch or container type (53).

6.4.10 Travel blanks are the contents of a sample container handled in the same manner as those containers holding samples, except that there has been no sample inserted into the travel blank. The purpose for travel blanks

is to audit sample integrity for loss due to sample handling and transport. Travel blanks are useful when analysis is performed at an off-site laboratory. The results obtained by analysis of travel blanks can be used to indicate a potential need to modify sample handling and transport procedure. At least one travel blank should be included in each batch of samples.

6.4.11 Sample container blanks are obtained by sampling the contents of a clean sample container to ensure that residual contaminants are not present in the container prior to sample collection. If contamination is detected in the cleaned containers, the decontamination procedure must be modified to remedy the problem. Sample container blanks should be collected and analyzed prior to each use of a sample container.

6.4.12 Sample probe blanks, consisting of carrier gas or atmospheric air contrasted to atmospheric air blanks, are drawn through the sampling device and recovered in the same manner as soil gas. The purpose for sample probe blanks is to check for the presence of sample train contaminants that would impact data quality. If contaminants are detected in sample probe blanks, the decontamination procedure must be modified to remedy this condition. Sample probe blanks should be collected and analyzed prior to each use of a probe and/or other components of the sampling system.

6.4.13 Field replicates are recovered as separate soil gas samples collected from the same sample site into multiple containers. Field replicates can be used to estimate the combined precision of sampling and analysis. The recovery of field replicates is not a common practice. When field replicates are demanded by a client or as dictated by a particular situation, field replicates should be recovered as often as is economically and practically possible, however in no instance should the number of replicates fall below ten percent of the total number of soil gas samples (53).

6.4.14 Sample spiking, or the addition of a known quantity of a known compound or mixture to the soil gas sample, is sometimes performed in the field to provide internal checks of analytical quality. Sample spiking in the field is not recommended due to measurement uncertainties in the field. Moreover, caution must be exercised with this procedure because of the potential for contaminant interaction with the known compound(s).

6.4.15 A paperwork audit is recommended at the end of each working day or at the conclusion of recovery of each batch of samples recovered. The paperwork audit should be conducted by the document control officer and include evidence of an equipment inventory, sample inventory including QA/QC samples, review of field notes and chain-of-custody documentation.

6.4.16 Chain-of-custody documentation is recommended at all times, and is mandatory for soil gas surveys when samples are transmitted to an off-site laboratory. It is recommended for soil gas surveys when sample custody is transferred to someone other than the field team leader for any reason. Chain-of-custody documentation assures that samples have not been altered or mishandled prior to analysis. This procedure is mandatory for sample handling and transport in situations where there is likely to be a cost

**TABLE 2 Summary of Possible Causes of False Positive and False Negative Values<sup>a</sup>**

Result	Causes
False negatives, that is, falsely low values	Barriers to gaseous diffusion, such as perched water, clay lenses, impervious man-made debris, saturation of soil pores with water (as from rain), low subsurface temperatures.
	Biological or chemical degradation.
	Leakage or blockage in the sample train, improper purge procedure, loss of sample from sample container, problem with analytical system.
False positives, that is, falsely high values	Contamination in sampling train, sample container, or analytical system.
	Contribution of volatile organic contaminants from vegetation.
	Significant contamination in overlying soil.

<sup>a</sup> See Ref (32).







recovery effort or demonstration of contaminant responsibility in a court of law.

**6.5 Sample Handling and Transport**—Soil gas sampling and analysis usually involve the monitoring of contaminants at very low levels. Consideration of sample handling and transport is not trivial to this exercise.

**6.5.1** The period of sample handling and transport represents the greatest opportunity for loss or gain of contaminants from or to sample containers. Loss occurs by contaminant condensation within the sampling train, sorption onto materials within the sampling train, solution into condensed water in the sampling train, chemical changes or leakage to the atmosphere through defects in the sampling apparatus or sample container. Gain of contaminants from sources other than the sampling horizon can occur through related mechanisms working in reverse. Both processes can severely limit the value of data obtained from a survey, and they must be minimized.

**6.5.2** In general, the time between sample collection and analysis should be minimized. Investigators should protect samples against light and heat, and exercise precautions against leaks (see Practice D 1605).

**6.5.3 Acceptable Materials**—Investigators are responsible for selecting materials for soil gas sampling, transfer and containment that will not impact sample integrity. Containers that have parts made from porous or synthetic materials such as PTFE, rubber or many plastics are likely to retain or contribute contaminants to soil gas samples. Corrosive metals such as steel or brass become difficult to decontaminate upon corrosion due to the increased surface area of the corroded material and its enhanced sorptive capacity. Septa of any material will be responsible for measurable contaminant loss over time due to leakage. Acceptable materials can be conveniently decontaminated prior to soil gas recovery. Materials that cannot be decontaminated effectively between samples must either be replaced between samples, considered in QA/QC planning as a survey limitation or abandoned in favor of more suitable materials.

**6.5.4 Integral Systems**—Problems of sample handling and transport are minimized by integration of the sampling and analytical system. For example, a whole air-active sampling system can be coupled directly to a portable VOC (volatile organic compound) analyzer. The sample stream is fed directly to the intake port of the analyzer and passed through the detector. If there are no system malfunctions in the sample path, problems of sample degradation become trivial.

**6.5.4.1** Care must be exercised with integral systems, however. The dead volume of integral systems is much higher than separate sampling and analytical systems. If the sampling system is not capable of delivering constant sample flow rates at or exceeding the requirements of the analyzer employed, data accuracy and comparability can be seriously affected. Moreover, a large sample volume is required merely to purge the sample system. In soils with moderate moisture contents or even nominal clay contents, it may not be possible to recover the volume of soil gas required to purge the system without serious negative impact to the composition of the soil gas sample recovered. Vapor phase contaminants can be lost to purge volume and atmospheric break-

through can occur, leading toward a false negative result. Although this problem may not be apparent in seriously contaminated environments, it can become a fatal flaw at low contaminant levels.

**6.5.4.2** Cross-contamination is a concern with integral systems. Many integral systems employ common elements from sample to sample, namely tubing, flow meters and analyzer components. Overcoming persistent contaminants can be difficult in integral systems, especially when high soil humidity and cold weather complicate the field effort.

**6.5.5 Transfer of Samples from Sampler to Container**—The method of transfer of samples from sampling device to containers is largely dependent upon the volume of soil gas recovered.

**6.5.5.1** Small volume samples are commonly recovered by syringe for immediate injection into an analyzer or small volume container. Glass gas-tight chromatography syringes are employed when rigorous QA/QC protocol is required and samples are injected into the analyzer immediately upon recovery. These syringes must be decontaminated prior to recovery of each sample aliquot. Disposable syringes are employed when samples are to be transferred to a small volume container for transport. They are inexpensive, commercially available and convenient to use. However, disposable syringes can present a disposal problem. They should be inventoried prior to use and destroyed after use, the number destroyed equalling the number inventoried and used. Destruction includes smashing the syringe cylinder and clipping the needle.

**6.5.5.2** Hand pumps are also used to transfer samples into tedlar bags or glass bulbs. Hand pumps are preferably installed behind the analyzer or container in the sample train to avoid contribution from or loss of contaminants to the hand pump. Hand pumps commonly contain petroleum-based lubricants which will contribute to the hydrocarbon content of soil gas. These devices must be placed at the end of the sample train or abandoned in favor of another tool.

**6.5.5.3** Large volumes of soil gas are commonly recovered by hand or mechanical pumps installed at the end of the sample train. Large volume systems can be metered for soil gas flow rate, which is controlled by the capacity of the vadose zone sampling horizon to transmit vapor to the sampling device, the volume and configuration of the sampling system and the requirements of the analyzer or sorptive trap employed.

**6.5.5.4** Small volume sampling is quite sensitive to variations in sample transfer technique. Septum coring by syringe is a common problem that restricts flow of soil gas through the needle. Coring can be corrected by decreasing the needle size and using a relatively hard septum material. Coring does not occur with side-port needles, a high-cost alternative. Needles of 25 to 27 gage seldom core septa. However, flow rates through these small gage needles are slow enough to require great care in consistency of sampling rate to minimize septum bleeding during sampling. This consistency is highly subjective and must be obtained through experience. Polypropylene disposable needles may provide opportunity for contaminant loss by sorption or gain by contribution to the soil gas sample. This can be minimized by using the polypropylene syringe to purge the sampling device prior to sampling, thereby reducing the potential for loss or gain of







contaminants to that of the sampling device. Luer-lock needles should be checked for tightness by twisting prior to each use.

6.5.5.5 Tubing is commonly used in large volume sampling. For low level detection, tubing can present a cross contamination problem if not replaced in the sampling train prior to sampling at a new location. Some particulate matter and condensate may be trapped in tubing prior to entry into the flow meter and analyzer by looping the tubing into three or four small diameter loops at a point near the sampling device. This can eliminate the need for water traps or particulate filters in the system that can contribute to system loss or gain of contaminants.

6.5.5.6 Vacuum can be employed to transfer soil gas from a sampler to a container. Evacuated glass bulbs, some containing adsorbents or absorbing liquids (see Practice D 1605), can be affixed to an in-place and purged sampling device and allowed to come to pressure equilibrium. Care must be exercised in recovery of the gas sample from a vacuum cylinder. Upon recovery, the sample is immediately subjected to negative pressure and atmospheric contamination of the sample is encouraged.

6.5.6 *Sample Collection: Containers*—A wide variety of sample containers is employed by field investigators. Container selection is based upon the physical properties of the contaminants sampled, the volume of the sample recovered, the physical properties of suspected contaminants, the sampling system employed, the anticipated sample holding time prior to analysis and the analytical method chosen. Container type for a soil gas survey should be held constant within the survey. A change in container type can impart bias to a portion of the data due to sorptive or desorptive processes related to container type.

6.5.6.1 Whole air samples can be contained in any device made of suitable materials (see 6.5.3) that conveniently satisfy survey, handling, transport and analytical requirements. Certain containers require special handling practice. The literature provides discourse on atmospheric sampling bags (54).

6.5.6.2 Sorbent traps are commonly self-contained. Care must be exercised to select a trapping device that is compatible with the properties of the target compounds and the technique of desorption chosen. Good practice for use of these devices, including handling and desorption procedure is required for successful implementation of sorbent traps when sampling organic compound vapors (see Practice D 3686).

6.5.6.3 Table 2 provides an inventory of sample containers, their applications, advantages and limitations (32).

6.5.6.4 Containers exist that provide for both whole-air and sorbent fractions as well as removal of sample by displacement (see Practice D 1605). Some are convenient for field use, however most are too complex or fragile to be of effective use for a field screening technique requiring rapid mobility.

6.5.6.5 Detector tubes should not be considered as a primary containment vehicle for the purpose of storage and transport of soil gas. A discussion of detector tube application is provided in 6.6.1.

6.5.6.6 Containers for soil samples to be preserved for a subsequent headspace analysis range from glass sample vials

to metal cans. The choice of container for soil headspace determination is dependent upon the method of sampling chosen. For soil samples obtained by backhoe, bucket auger or other destructive technique, that is, a disturbed sample, extrusion into a sample vial is not necessary since most of the highly volatile components have already been lost through the act of soil sampling. Metal cans should be made from a material that does not rust. Coating materials and sealing waxes are likely to react with or adsorb soil contaminants, presenting limitations to the value of the data collected. Glass containers with screw threads or crimped seals are difficult to use for soil headspace methods due to the inability of investigators to consistently, thoroughly and rapidly clean the threads or crimp surfaces of all containers prior to capping.

6.5.6.7 Soil pore liquid headspace samples are whole-air or whole-air plus pore liquid samples. They may be contained in most devices suitable for whole-air containment, however investigators are cautioned to select containers from which a vapor sample can be extracted for analysis independently of the liquid present.

6.5.7 *Sample Processing*—Some investigators process soil vapor samples prior to analysis. Processing is performed in an effort to control sample degradation in containers. Efforts to check this degradation by sample processing include refrigeration, pressurization, and pasteurization. As a general practice, sample processing is strongly discouraged. Refrigeration may be somewhat effective in controlling sample degradation, however the best method is to limit or avoid soil gas sample storage whenever possible. The limited shelf life of soil gas samples is discussed in 6.5.9.

6.5.7.1 Extraction is a sample processing step used to remove soil contaminants from soil cores or other similar samples. This technique can efficiently recover contaminants from all residence phases, not just the vapor phase. As a result, the technique yields samples that are not representative of soil atmosphere contaminant suites.

6.5.8 *Sample Transport*—If samples are to be transported to an off-site laboratory for analysis, they must be properly packaged to avoid damage to sample containers. Care must be taken to keep samples from becoming overly warm or agitated during transport. Overnight air express is highly convenient if samples are properly contained, but air freight is not recommended if samples are held in containers such as gas tight syringes or tedlar bags. These containers have other limitations as discussed in 6.5.6.

6.5.9 *Sample Life*—Soil gas samples have limited shelf life even in the most effective containers. Soil gas sample life is strongly container dependent. Numerous factors limit shelf life; most involve degradation in a container. Exposure to light, heat and agitation during shipping will accelerate sample degradation. Biodegradation may occur in some sample containers if water vapor condenses in a container containing microorganisms capable of metabolizing contaminants as substrate.

6.5.9.1 The safest practice is to minimize sample storage time. This problem is greatest when off-site laboratories are engaged to analyze the samples. Prior to recovering the soil gas samples, arrangements can be made with the selected off-site testing laboratory to schedule the necessary personnel and equipment in anticipation of sample delivery.







**6.5.10 Soil Gas Archiving**—Sample archiving in anticipation of a future analytical or descriptive requirement is a common practice. Minimal effects of degradation or loss may be noted in storing certain sorbed samples. Soil gas archiving is, however, not recommended. Although dependent upon the type of container and the storage environment, the likelihood of degradation of soil gas samples is great enough to raise concern. Insertion of standard gases into an archived sample set and spiking of archived soil gas samples with standards provides a reference to determine the likelihood or extent of sample degradation.

**6.6 Analysis of Soil Gas Samples**—Soil gas analysis procedure is based upon pre-existing protocol established for the analysis of contaminants in ambient air. A common reference practice defining terms, sampling information, calibration techniques and methods for validating results may be applied to all automatic analyzers (see Practice D 3249). Basic laboratory practice common to investigators engaged in sampling and analysis of atmospheres applies to soil gas analysis. Note that air sampling protocols and soil gas sampling protocols are not equivalent: geophysical and geochemical factors as well as definition of air sample volume contribute to this lack of equivalency. This guide includes the criteria, guidelines and recommendations for analytical segments including the mode of operation of the laboratory and data validation (see Practice D 3614).

**6.6.1 Basic Analytical Approach**—Soil gas analysis is performed to identify the presence of contaminants, their type and relative concentrations. Various analytical methods are highly general, satisfying only the most rudimentary requirements of contaminant screening. Others are sophisticated, providing identification and relative concentration information for numerous chemical compounds determined to be present in a soil gas sample. The choice of basic analytical approach in soil gas analysis is driven by the purpose of the soil gas survey, quality assurance objectives and budgetary constraints placed upon investigators.

**6.6.1.1 Soil gas surveying as a field screening technique** can often be effective without the commitment of expenditure for highly sophisticated techniques. This survey purpose is merely to locate other, more direct, techniques. Caution is suggested when choosing highly sophisticated analytical methods for field screening by soil gas monitoring. This selection is controlled largely by the need for the analytical method chosen to be cost-effective.

**6.6.1.2 Other applications of soil gas monitoring** require more thorough analytical protocol. It is not possible, for example, to suggest the locations of partitioned miscible and immiscible ground-water contaminant plumes with elementary analytical systems. Moreover, the independent monitoring of multiple classes of contaminants in soil gas normally requires analytical systems with multiple detectors. Successful soil gas monitoring for petroleum exploration requires an analytical system which can separate and identify extremely similar volatile compounds occurring at very low concentration levels.

**6.6.1.3 Contaminant concentrations in soil gas** can vary from levels below the detection limit of the most sophisticated equipment to percent of a whole-air sample. Ideally, the analytical system chosen has enough flexibility to determine contaminants in a wide range of concentrations. Care

should be taken to select an analytical system sensitive enough to avoid false negative results which can lead to invalid conclusions. Many analytical systems are not designed to perform to specifications in very high concentration environments, requiring sample dilution prior to analysis or selection of a less sensitive method.

**6.6.1.4** Of primary importance to the successful analysis of soil gas is the familiarity and experience of the analyst with the analytical system chosen. The analyst must be able to independently care for and maintain the equipment as well as recognize symptoms of procedural error. The success of an analytical effort lies wholly with operator ability and experience. Excessive machine capability cannot compensate for operator inexperience.

**6.6.1.5** Soil gas may be analyzed by a number of methods, including portable VOC (volatile organic compound) analyzers, gas elution chromatography, gas chromatography-mass spectroscopy, and colorimetric and color-indicating detector tubes. Infrared spectroscopy and fiber optic chemical sensors can be applied to soil gas analysis, however their use is currently limited and few investigators have experience with this instrumentation. In practice, gas chromatography (GC) or GC-based handheld detectors are the most widely used analytical instruments (32) for soil gas analysis. This guide uses numerous terms relating to various GC methods for soil gas analysis. Most of the terms should apply to other GC methods (see Practice E 355).

**6.6.1.6** Portable VOC analyzers used for fugitive emission screening and industrial hygiene monitoring have been adopted for soil gas analytical purposes by numerous investigators. These devices are easily transported to and from the field, require minimal operator skill, provide immediate data and serve to eliminate many sample handling and transport steps which can result in uncertainty. Portable VOC analyzers are limited in application to very low level detection due to the absence of a concentration step. They exhibit limited selectivity and do not have the ability to separate contaminant compounds, leading to potential interference. These devices also are limited in accuracy due to the inability to calibrate for the wide variety of contaminant compounds encountered in soil gas, each compound having its own character of detector response. Portable VOC analyzers contain three types of detectors. These are the flame ionization detector (FID), the photoionization detector (PID) and the infrared (IR) detector. The literature contains a thorough treatment of these devices (10, 55).

**6.6.1.7** Soil gas analysis by GC is by far the most versatile and the most costly soil gas analytical method. Instrumentation can be varied to accommodate field mobility, however this is not always required. The technique provides separation of compounds in a chromatographic column, tentative identification of compounds determined to be present and a relative quantitation of compound concentration based upon comparison to a known standard. Soil gas is introduced into the GC and conveyed through a chromatographic column by a carrier gas, separating the contaminants as they pass through the column. The separation is obtained when the sample mixture in the vapor phase passes through a column containing a stationary phase possessing special adsorptive properties. As the gas stream emerges from the column, it passes through a detector, providing for measurement of a







specific sample property through the recording of detector electrical response. These responses, or peaks, are recorded as a function of time. Comparison of known standard compound response time with the response time of an unknown represented by a peak results in the tentative identification of the unknown. Comparison of the magnitude of detector response to the newly identified compound versus detector response to the same compound of known concentration, a laboratory standard, results in a relative quantitation of subject compound concentration in the sample.

6.6.1.8 Gas chromatography is essentially a physical separation technique. The degree of separation depends upon the differences in the distribution of volatile compounds, organic or inorganic, between a gaseous mobile phase and a selected stationary phase that is contained in a tube or GC column (see Practice E 260).

6.6.1.9 Numerous factors can impact the ability of the GC to determine contaminants in a soil gas sample. These include column characteristics, sample flow rate, sample temperature, the composition of the carrier gas and the type of detector employed. Instrumentation can be expanded to include multiple columns, multiple detectors, sample loops and temperature programming, all of which make an instrument more versatile, albeit at additional cost.

6.6.1.10 Simple GCs are portable analyzers with GC options. Field GCs are more advanced instruments with temperature programmable ovens and provide opportunity for multiple columns and detectors. They can be carried in mobile laboratories or established in a temporary base laboratory in the field. Research-grade instruments are normally based at off-site laboratories with strictly controlled environments. These are used when positive identification or very low detection limits are specified. The literature contains excellent comparisons of the advantages, limitations and applications of the various configurations of GCs, including instrument specifications (10, 32, 56, 57).

6.6.1.11 Detector tubes have been applied to safety and health atmospheric monitoring, agriculture and the chemical industry. These devices are designed to be compound specific, although this characteristic is dependent upon the contaminant compounds present in the sample drawn through the tube. Detector tubes may be used for short-term sampling (grab sampling; 1 to 10 min) or long-term sampling (dosimeter sampling; 1 to 8 h). Short-term sampling involves the movement of a given volume of gas through the tube by a mechanical pump. If the substance for which the detector tube was designed is present, the indicator chemical in the tube will change color (stain). The concentration of the gas may be estimated by either the length of the stain compared to a calibration chart or by the intensity of the color change compared to a set of standards (see Practice D 4490). Long-term sampling involves the movement of gas at a very slow rate through the tube by means of an electric pump. The use of long-term detector tube sampling for soil gas monitoring is limited to specific temporal survey designs.

6.6.1.12 Detector tubes are relatively inexpensive and provide immediate results. Their use is restricted to applications with few interfering compounds. Depending upon the contaminants present, they may be of low sensitivity and can be affected by humidity, normally high in soil gas, sample

flow rate, temperature extremes (32), storage conditions and shelf life.

6.6.1.13 The literature contains excellent discourse on the detector tube apparatus, reagents, procedure accuracy and amenable compounds (see Practice D 4490).

6.6.2 *Specific Analytical Approaches*—This subsection discusses various detectors and methods that may be integrated into soil gas analytical instrumentation. For methods providing detector alternatives, the choice of an appropriate detector should be guided by knowledge of detector properties. Key properties are as follows (after Mayer, 1989 (32)):

6.6.2.1 *Selectivity or Specificity*—Selectivity refers to the responsiveness of the detector to the compound of interest. Detectors responding to a wide range of classes of compounds are termed universal or non-selective detectors. Those that respond to only certain classes of compounds are termed selective detectors.

6.6.2.2 *Sensitivity*—Sensitivity refers to the relationship between the detector response and the quantity of the subject compound injected. It is the smallest detectable quantity of a compound; it is usually considered to be the amount that produces a response equal to twice the baseline noise of the detector.

6.6.2.3 *Linear Dynamic Range*—Linear dynamic range is the range over which the detector response to a compound is directly proportional to the amount of compound injected. Detectors vary in the range of component concentrations over which they are linear. Wide linear dynamic range is desirable because it simplifies quantitation of samples having widely varying ranges of concentrations.

6.6.2.4 *Stability*—Stability is a factor referring to detector responsivity over time. Stability is controlled by numerous factors and is seldom quantified. The required frequency of instrument calibration is determined by detector stability.

6.6.3 Specific analytical approaches are as follows:

6.6.3.1 *Flame Ionization Detectors (FID)*—Flame ionization detectors generate electric current when gases containing carbon atoms are oxidized to carbon dioxide in a hydrogen flame and potential is applied across the flame. The magnitude of the electric current generated is termed the detector response. FIDs are responsive to hydrocarbon contaminants in soil gas and are commonly employed for this purpose. These detectors are durable for field application, and have a wide linear range and nearly uniform response to organic gas species. FIDs are generally unresponsive to inorganic gases and water vapor, common constituents in soil gas. FID performance can be evaluated independently of the chromatographic column (see Practice E 594). Although highly versatile, these detectors are not selective for halogenated compounds. They require supplies of fuel gas which require careful safety practices in handling and flame ignition.

6.6.3.2 *Photoionization Detectors (PID)*—Photoionization detectors employ ultraviolet radiation to ionize contaminant molecules. Positive ions and free electrons are formed which migrate to the detector electrode(s), resulting in an electric current that is proportional to contaminant concentration at the detector. PIDs are extremely sensitive to aromatic hydrocarbons due to the great efficiency of ionization of pi bonds under ultraviolet radiation. Efficiency of ionization of sigma bonds is lower, resulting in a higher PID detection limit for aliphatic hydrocarbons. The selectivity of







the method can be adjusted by selecting lamps of different energies, causing a change in response of contaminants with fixed ionization potentials to changing lamp energies. Tables exist of ionization potentials of compounds within classes common to soil gas contaminants (58). Methane has an ionization potential higher than the energies of commercially available lamps, limiting the PID to detection of compounds other than methane. PIDs are further limited by their tendency to conceal the presence of low-sensitivity compounds when high-sensitivity compounds (aromatics) are present. PID response can be impacted by condensation of water vapor in the lamp.

6.6.3.3 *Electron Capture Detectors (ECD)*—Electron capture detectors are highly sensitive to and selective for compounds with electronegative functional groups such as CFCs (chloro-fluorocarbons). The sensitivity of the detector is proportional to the number of these groups on a compound, resulting in a unique detector response to each compound. The ECD comprises a source of thermal electrons inside a reaction chamber (a radioactive source emits  $\beta$  radiation which ionizes the carrier gas to produce electrons). The device detects compounds with electronegative functional groups capable of reaction with thermal electrons to form negative ions. Such reactions cause a decrease in the concentration of free electrons. The detector is designed to measure changes in the concentration of these electrons inside the chamber (see Practice E 697). Calibration of the ECD is therefore linked to each compound to be determined by the detector. ECDs are also sensitive to water, oxygen and other common components of soil gas, causing potential problems in method performance. ECDs emit  $\beta$  radiation that should be properly vented. Operation of an ECD requires licensing under Federal regulation.

6.6.3.4 *GC/Mass Spectroscopy*—Combination of gas chromatography and mass spectroscopy results in the GC/MS method of analysis. A mass spectrometer is used to obtain a mass spectrum of each eluting compound. Positive identification of these compounds is sometimes obtained by comparison of the unknown mass spectrum to a library of known spectra. GC/MS can be extremely selective for target compounds. Use of the technique for soil gas monitoring is limited, primarily due to the cost of analyses.

6.6.3.5 *GC/Fourier Transform Infrared Spectroscopy*—This analytical method combines gas chromatography with Fourier transform infrared spectroscopy. GC/FTIR can provide a rapid identification of eluting compounds by comparison of their infrared spectra with a known spectral library. Quantitation is achieved by subsequently passing the sample through an appropriate GC detector such as the FID or ECD. This method, like GC/MS, is limited in application to soil gas monitoring by the high cost of analysis.

6.6.3.6 Other detectors are applied to soil gas analysis by GC, albeit rarely in comparison to FID, PID and ECD. They include the argon ionization detector, a non-destructive device similar in operating design to the ECD, the flame photometric detector (FPD) used to determine organic compounds containing sulfur and phosphorus, and the hot-wire (pyrolyzer) used to determine compounds containing nitrogen.

6.6.4 *Analytical QA/QC*—The validation of the analytical aspects of soil gas monitoring is fundamental to the tech-

nique. Analytical equipment and procedure must be evaluated by laboratory QA/QC, just as the sampling system, sampling plan and field procedure are evaluated by field QA/QC methods. Analytical QA/QC defines a confidence limit of performance. The utilization of well tested and uniform analytical practices is essential to the production of reliable and defensible data, the validity of which can be demonstrated at a later date through the use of written field and laboratory records (see Practice D 3614).

6.6.4.1 Most analytical QA/QC plans contain calibration steps, linearity checks, standard analyses, blank analyses, duplicate analyses and audit checks. The various analytical approaches discussed in 6.6.3 require a variety of different protocols which will satisfy the QA/QC requirements for each method. Four types of analytical QA/QC samples are required for determination of quality assurance. These are analytical reagent blanks (used to determine the potential of sample or standard contamination from a reagent), laboratory blanks (used to determine the impact potential of the laboratory atmosphere on analytical results), analytical sample replicates (used to estimate the analytical precision for samples) and analytical standard replicates (used to estimate the analytical precision for standards). Table 3 provides a summary of suggested calibration and quality control requirements for analytical systems (10).

6.6.4.2 The aspects of bias, precision, representativeness, completeness and comparability must be considered to evaluate analytical equipment performance, including the establishment of minimum detectable quantities of contaminant compounds, retention time drift and the linearity of instrument response. Bias and precision must be quantified in order to compare actual survey performance with goals established in the survey plan.

6.6.5 A data validation summary report is a common method of evaluating analytical system performance. A guide for determining parameters key to the data validation summary report is provided as follows.

6.6.5.1 *Bias*—For determination of bias, the percent recovery can be determined using the following formulas:

$$\text{recovery reproducibility} = (DCS/KCS) \cdot 100 \quad (6)$$

where:

DCS = determined concentration of standard, and

KCS = known or certified concentration of standard.

The standard deviation of all standards analyzed can be determined as follows:

$$SD = \{(\text{sum}(\text{recovery}-i - \text{recovery-ave})^2)/(n-1)\}^{0.5} \quad (7)$$

Finally, the range of uncertainty can be determined using the following equation:

$$\pm R = \pm t \cdot (SD)/(n^{0.5}) \quad (8)$$

where:

$t$  = the value of Studentized  $t$  at the 90 % confidence level and  $(n-1)$  degrees of freedom.

The bias statements for data collected should be expressed as the average recovery plus or minus the range.

6.6.5.2 *Precision*—For the determination of precision, the relative standard deviation of replicates can be calculated using the following equation:

$$RSD\text{-pair} = SD/\text{Mean} \quad (9)$$







TABLE 3 Soil Gas Sampling Containers<sup>4</sup>

Type	Applications	Advantages	Limitations
Stainless steel canisters	Collection of samples for delayed analysis	Durability Ease of sample handling Can be re-used Sample holding time longer than that for other whole-air sample containers Sample volume measurement not required Desorption not required Allows replicate analysis	Expense Requires vacuum pump or gage Can be difficult to decontaminate
Glass bulb	Collection of samples for delayed analysis	Glass is more inert than other sample container materials Septa possible Allows replicate analyses	Easily breakable Leakage through stopcocks or septa possible Adsorption to PTFE or other parts
Bag	Collection of samples for delayed analysis Sampling of very high vapor pressure compounds for which absorption methods are unsuitable	Bulk loss of sample is readily apparent Containers are light-weight and easy to handle Sample volume measurement not required Desorption not required Allows replicate analyses	Expense Some compounds may be lost through or adsorbed to bag walls Some container materials may contaminate samples Containers cannot be easily re-used Leaks in valves
Syringe <sup>a</sup>	Collection of samples for on-site analysis	Ease of sample collection Does not require special equipment to introduce sample into GC Desorption not required	PTFE plungers can adsorb sample Holding time short due to leakage or absorption Sample volume smaller than for other containers
Sorbent sampler	Allows concentration of low level samples If samples are solvent-desorbed, allows analysis of liquid sample	Ease of handling Relatively long holding time	Requires precise sample volume measurements Sorbent type must be tailored to compounds to be measured; adsorption behavior of each compound for solvent used must be accounted for Requires desorption (thermal or solvent) for analysis

<sup>a</sup> See Ref (32).

<sup>b</sup> Syringes may also be used to transfer samples from the sampling device to a container for off-site analysis.

$$RSD-ave = \{((\sum(RSD-pair))^2)/(n-1)\}^{0.5} \quad (10)$$

where:

*RSD-pair* = relative standard deviation for each pair of replicates, and

*RSD-avg* = relative standard deviation overall.

Next, the precision can be determined as follows:

$$precision = \{(t \cdot RSD-avg)/DF\} \cdot 100 \quad (11)$$

where:

*precision* = the percent precision.

*t* = the *t* value for *n* - 1 pairs of replicates, and

*DF* = the degrees of freedom = (*n* - 1).

Finally, mean value is reported with associated uncertainty:

$$x \pm (x \cdot t \cdot SD-ave)/(DF)^{0.5} \quad (12)$$

where:

*x* = reported chemical concentration, and

*t* = the value of *t* at the 90 % confidence level for the appropriate degrees of freedom.

6.6.5.3 *Representativeness*—Representativeness is determined by the results of the cross contamination blanks and the air blanks. The results should be presented as a bias estimate, as follows:

$$bias (\%) = \{(CCC - CA)/Mean\} \cdot 100 \quad (13)$$

where:

*CCC* = concentration in cross contamination sample,

*CA* = concentration in air, and

*Mean* = mean concentration in sample set (bias may also be expressed for a single sample by substituting sample concentration).

6.6.5.4 *Completeness*—The completeness goal is 90 % or

higher. Completeness is the number of samples collected that can be validated through the procedures for bias, precision, and representativeness.

6.6.5.5 *Comparability*—Comparability is based upon professional judgment and is provided through planning steps carried out prior to initiation of field work.

6.7 *Data Interpretation*—Soil gas data interpretation is an iterative process including the examination of the raw data, selection of appropriate and useful data displays, and establishment of correlation of the data set to other vadose zone monitoring data and ground truth. Interpretation of soil gas data is not like other interpretive exercises involving measurement data, in that mathematical expressions relating soil gas contaminant concentrations to underlying soil, rock and ground-water contaminant concentrations cannot be written for most applications at a high confidence level. This is a function of a lack of site characteristics information at even the most comprehensively studied sites. Soil gas data cannot be consistently interpreted in a manner that establishes direct correlation between contaminants in a soil gas horizon and contaminants in other horizons. Processes including migration and degradation can have profound influence on the correlation of soil gas data to ground truth. Interpretive efforts excluding consideration of these influencing processes can be highly misleading. For example, the presence of contamination in an underlying horizon will not necessarily correlate to the detection of contaminants in overlying soil atmospheres, that is, the potential for a false negative result. The converse is also true, that is, the potential for a false positive result. Interpretation of GC results in the laboratory without consideration of pertinent hydrogeological informa-







tion may lead to incorrect conclusions (59). However, the detection of contaminants in soil gas does suggest the existence of a contaminant source, and increases in contaminant concentration can suggest close proximity to the source or an increased quantity of the subject contaminant in the subsurface. It is the responsibility of the interpreter to examine soil gas data in context of other site characteristics, and provide an interpretation based upon sound judgment and thorough yet practical data treatment.

**6.7.1 Manipulating Data**—Soil gas data is normally interpreted as raw data. The application of correction factors is not recommended, as it is difficult if not impossible to determine if the magnitude of the correction factor is greater than that of the variance between data populations in a survey. Moreover, the need for correction factors can indicate a flaw in survey design, sampling system performance or the objectivity of the interpreter.

**6.7.2 Defining Data Subpopulations**—Soil gas monitoring seeks to define anomalous subpopulations of data that contain measurable quantities of contaminants or unusual compositions. These populations can easily be described by their contrast to normal populations, for example, contrasting populations with and without measurable contaminants. Establishment of contaminant baselines or conditions "at background" make this contrast possible. If all soil gas samples are recovered in a contaminated area, there may be no apparent contrast.

**6.7.2.1 Statistical treatment of soil gas monitoring data** allows the interpreter to estimate the amount of variation noted in the survey data due to errors. This practice also permits the interpreter to evaluate the data quality objectives suggested for the survey during the planning phase. Statistical treatment of soil gas data can also be of use to define anomalous data subpopulations when the boundaries of a contaminated area are not clearly defined or if the existence of multiple populations of data (that is, contaminated and uncontaminated) within a single data set is in doubt. The literature contains discourse on statistical treatment of soil gas data (10, 60).

**6.7.3 Interpreting Soil Gas Data Profiles**—Soil gas data from survey profiles displayed on an  $X - Y$  plot is an effective aid to data interpretation. This display is useful to examine the overall context for soil gas measurement data potentially indicating contamination. If the profile is displayed as a cross section through a grid pattern or as a linear array of sample points, the profile display can illustrate spatially significant groupings of data subpopulations.

**6.7.3.1** It is quite common for concentration data to be highly variant within a contaminated area. Soil gas profiles can be used to show variation in spatially related data. This is one method of defining subpopulations of data indicating contamination or other anomalous characteristics.

**6.7.3.2** Multiple data sets can be displayed on a single profile. Comparison of one data set to another on a single profile is a simple visual method to screen for suggested data subpopulations. Comparison of concentration data and compositional data (see 6.7.5) on a single profile can further resolve this problem.

**6.7.4 Mapping Soil Gas Data**—Soil gas data obtained by sampling at a single depth is often mapped to suggest the lateral extent of subsurface contamination. Map suites of soil

gas data obtained from multiple depths can sometimes aid investigators in determining the depth to the contaminant source.

**6.7.4.1** Numerous algorithms can be used to interpolate between data points, including linear, inverse distance squared, inverse distance cubed, splines and kriging. The various interpolation methods will yield similar results, suggesting a general pattern of contaminant distribution in soil gas. Kriging requires a probability model for each survey site mapping application for which it is employed, the derivation of which requires data which are not normally available for a given soil gas survey area.

**6.7.4.2** Caveats exist in using computer mapping programs as interpretive aids. Difficulties can arise in treatment of adjacent data points differing in contaminant concentration by an order of magnitude and more due to vapor migration barriers, preferential vapor flow paths or changes in soil moisture or porosity content. It is possible to model these characteristics and input such a model into some computer mapping programs, however this introduces bias into the mapping effort. Single point soil gas contaminant concentration highs may exist due to a sample density which is insufficient to resolve the cause for the single point anomaly. Contour mapping of such data may be meaningless without the complement of other information, especially detailed knowledge of site characteristics.

**6.7.5 Analyzing the Composition of Soil Gas Contaminants**—Certain applications of soil gas monitoring require detailed analyses available from off-site bench laboratories or mobile laboratories. Determination of a number of contaminant compounds in a soil gas sample set with either of these analytical systems enables the interpreter to make a comparative analysis of the changes in soil gas contaminant composition within that sample set.

**6.7.5.1** Compositional analyses can range in scope from a simple listing of the various compounds determined in each sample to thorough data treatments. Profiles of soil gas data can be constructed to illustrate the spatial relationship between two potentially different groupings of data (see 6.7.3). Crossplots of contaminant compound concentrations are highly effective in the definition of data subpopulations, and can be used to relate contaminant types to known on-site waste streams and sources in complex settings. Known as fingerprinting, this guide compares vapor composition over a known contaminant product and the known soil atmosphere composition over that product to soil gas contaminant composition in areas being investigated on the subject site. Subtle divisions in data subpopulations can be defined by crossplots of contaminant ratios. In addition to simple ratioing, computerized multivariate pattern recognition techniques such as cluster, factor and discriminant analyses can assist in the evaluation of intra-data set compositional variations and their relationship to the physical contamination issues at a site.

**6.7.5.2** Soil gas data can be examined for the appearance of target compounds determined to be present in contaminant mixtures. The success of this practice, used primarily to establish the location and extent of underlying ground water contamination, relies upon selection of appropriate target compounds and the persistence of target compounds in soil vapor.







6.7.5.3 Monitoring specific compounds in soil gas data can be utilized to determine the progress of degradation or migration of contaminants in the vadose zone and in ground water. Biodegradation has been monitored by the appearance of excessive quantities of carbon dioxide in soil gas (61).

6.7.6 *Interpretation in Context of Other Vadose Zone Monitoring*—Soil gas monitoring is not a technique that can consistently support conclusions based upon interpretations of survey results. For this reason it is strongly recommended that other vadose zone monitoring methods be used to corroborate data obtained from a soil gas survey, especially when investigators are attempting to do more than simply audit a subject site for the presence of contaminants. Useful models of contaminant emplacement and transport in the vadose zone can be constructed by combining techniques. Examples of useful combinations are soil pore liquid and soil gas monitoring or neutron probe and soil gas monitoring.

6.7.7 *Correlation With Ground Truth*—Interpretation of soil gas data is difficult without establishing some form of ground truth with which to substantiate survey results. Ground truth can be in the form of monitoring well data, for purposes of determining the extent of contamination by a ground-water contaminant plume. Examples of other forms of ground truth usable in support of soil gas data interpretation are soil cores, the presence of contaminant odors in basements, observed floating contaminants in storm sewers or utility vaults, or other field observations.

## 7. Data Reporting Requirements

7.1 *Purpose of Reporting*—Of primary concern in a report of findings pertaining to a soil gas survey is that the report includes the information necessary to describe the results of that survey performed for a particular application. In many instances, certain interpretative methods or data reporting formats useful to end users for one particular application are not relevant to the needs of end users applying the information to a different application. Examples of these differing applications that require unique report subject matter are soil gas contaminant determinations for real property environmental assessments, soil gas monitoring of volatile organic contaminants from underground storage tanks and soil gas sampling as a tool useful in the exploration for natural resources. Certain applications require a thorough treatment of a significant number of factors impacting the meaning and usefulness of soil gas data interpretations. Examples of such applications include damage assessments, contaminant source identification or tests of the effectiveness of remediation. Other applications command minimum reporting requirements. An example of such an application is the monitoring of releases from underground storage tanks over time. Included in a discussion of the report objectives should be an identification of the end user category (for example, regulatory agency, land acquisition negotiations).

7.1.1 A decision must be made regarding the units expressed in reporting, that is, qualitative or quantitative. If quantitative, the appropriate expression of units in volume/volume or weight/volume must be determined. SI units are recommended for reporting of atmospheric measurement data (see Practice D 1914).

7.2 *Report Format*—Certain reporting requirements are commanded without regard to data application. In large part

they are related to the QA/QC objectives, and include data comparability, representativeness, bias, precision accuracy, completeness and analytical detection limits whenever possible. At a minimum, a general discussion of the reliability of results and analytical detection limits is warranted; soil gas test data may be evaluated in the same manner as is other atmosphere test data (see Practice D 3614).

7.3 *Salient Points to be Addressed in Reporting*—The report of findings of any soil gas monitoring effort can contain discussions within any number of topics that should be selected to best suit the requirements of the end user. Selection of appropriate topics is discretionary, usually based upon a scope of work determined by prior agreement between the data provider and the data end user. Efforts to limit reporting requirements for the sake of short term time and money cost savings usually result in low-confidence level treatment of the report or an ultimate time and money cost gain, or both. Discussions that should be included when appropriate and whenever possible are provided below.

7.3.1 The purpose of the soil gas study should be stated, as well as the rationale for selection of a particular soil gas monitoring technique.

7.3.2 Selection of a particular soil gas monitoring technique is typically controlled by the chemical and physical properties of the chemical compounds of interest which are known to occur or suspected to occur on site. A discussion of the sample array in three dimensions, sampling method employed and the analytical scheme chosen in context of these properties should be provided.

7.3.3 The rationale for selection of a particular soil gas monitoring technique should always be based upon the physical properties of the vadose zone as well as the chemical and physical properties of the compounds of interest. A discussion of the impact of these vadose zone properties on survey design should be included in the report. The regional and local hydrogeologic conditions within the survey area should be described. A discussion of the regional geology should include the physiographic province, a generalized geologic column, geologic structure and general ground water occurrence. The local conditions should be described with regard to soil type(s), moisture content in the vadose zone, soil/bedrock interface, stratigraphy and lithology, ground water bearing zones, flow directions and gradients, potentiometric levels, aquifer characteristics and ground water quality.

7.3.4 If known and appropriate, the characteristics of a contaminant source or spill should be addressed. Examples of such characteristics are contaminant composition, the likelihood of single or multiple contamination events or the reaction potential (above, within and beneath the vadose zone) of multiple contaminant mixtures.

7.3.5 Every subject of every vadose zone monitoring effort has unique characteristics. Those characteristics that could impact the results of the soil gas monitoring effort should be described to provide a meaningful context in which to interpret the soil gas data.

7.3.6 There are a number of topics common to most soil gas data reporting that are useful in the majority of applications. The regional and specific site location should be identified using a site plot plan. The site plot plan could include an insert showing the regional location. A discussion







should be included regarding the physical structures at the site that may impact the location of sampling points and the migration of soil gas, for example, asphalt and concrete pads, buried pipelines and surface water impoundments. Site history must be considered, including the types of chemical compounds known or suspected to have been used at the site. These compounds should be listed with their chemical and physical properties as they relate to volatilization, solubility and other migration characteristics or soil gas recovery characteristics.

7.3.7 The site should be evaluated in the report of findings for the impact of the regional and local hydrogeologic conditions within the survey area on the results of the survey.

7.3.8 A detailed description should be given of the type of soil gas survey conducted. Details should include selection of active or passive method, whole air or passive sample collection method, sampling array, background sampling, equipment decontamination procedure employed prior to the survey, field or laboratory analytical methods and QA/QC procedures. Any unusual conditions should be noted, such as rainfall events during the course of the survey (especially when moveable soil gas chiefly originates from vadose zone microporosity), high pressure or low pressure front movement across the survey area during the course of the survey (especially when moveable soil gas chiefly originates from vadose zone macroporosity), or visual observations of contamination at sampling points.

7.3.9 If a subject property is found to be contaminated, a separate discussion of soil gas characterization of uncontaminated or non-anomalous contiguous property should be provided in the report of findings. This can be useful in highlighting naturally occurring petroleum hydrocarbons in soil and in establishing a regional baseline of contamination.

7.3.10 Data collected during the field sampling and field or laboratory analyses should be compiled in table form and be included in a preliminary or final report, preferably as appendices. Such data should include a listing of sampling and analysis dates, soil/rock description at each sampling point, depth and diameter of sampling point, quantity of soil gas purged prior to sampling, quantity of sample extracted, chromatogram and/or mass spectra for each sample and a tabulation of QA/QC samples recovered.

7.3.11 The report of findings should include a discussion of the results of the QA/QC efforts, establishing performance within limits set prior to the survey. Data validation involves review of the data collected for the purpose of isolating spurious values (32). Systematic errors or bias can be

detected in this review. Suggestions should be made as to the origin of the errors or bias.

7.3.12 Results of analyses should be displayed on plan maps and should include sampling point locations, physical features, contours of equal concentrations of specific compounds or compound groups (for example, alkanes) and any necessary keys or other notes to guarantee map clarity. Cross-sections showing changes in contaminant concentration with depth and concentration profiles of more than one contaminant through several sample locations can be highly useful displays. The report should include text describing each map, cross-section or profile.

7.3.13 Whenever possible, discussion should be provided that correlates soil gas data to ground truth. The most common and widely accepted form of ground truth is data from ground water monitoring wells.

7.3.14 When appropriate, the report of findings should attempt to identify the source of the contaminants encountered in the soil gas survey.

7.3.15 The report should contain a section which discusses the conclusions drawn from the results of the soil gas study and any recommendations which seem appropriate to enhance the value of conducting such a soil gas study. Conclusions should include identification of the compounds detected, if any, an assessment of the appropriateness of the soil gas study method used, and any circumstances that may have significantly impacted the results of the investigation, such as weather conditions or equipment calibration. Recommendations should address need for establishing ground truth, extension of the study to adjacent areas of interest, the need for a different soil gas study method, actions to resolve questionable QA/QC results, or need for additional chemical analyses for contaminant identification.

7.4 *Disadvantages of Real-Time Reporting*—In actual practice, many end users request real-time reporting of soil gas data obtained from field-based laboratories. Presentation of such data presents the opportunity for misunderstanding by end users who are not familiar with the caveats presented by data not examined in light of the QA/QC program or site specific factors. Real-time reporting of soil gas data is therefore not recommended.

## 8. Keywords

8.1 contaminant; environmental monitoring; geochemistry; ground water; Henry's law; petroleum hydrocarbon; sampling; soil gas; unsaturated flow; vadose zone; vapor monitoring; volatile organic compound







**TABLE 4 Summary of Suggested Calibration and Quality Control Requirements for Analytical Systems<sup>a</sup>**

Type of Instrument	Detector Type	Type of Calibration/QC Test	Frequency	Gas Standard(s)	Acceptance Criteria	Corrective Action
Portable VOC (THC) Analyzer	FID	(1) Multipoint calibration (zero plus three upscale concentrations)	At start of program	Methane or other aliphatic compound	Correlation coefficient $\geq 0.995$	Repeat multipoint calibration after checking calibration dilution system
		(2) Zero (span) calibration	Daily	UHP Air or N <sub>2</sub> /Methane	Response factor agreement within $\pm 20\%$ of mean RF for multipoint calibration	(1) Repeat zero span calibration (2) If still unacceptable, repeat multipoint calibration
		(3) Control sample analysis	Daily, prior to testing	Methane	Measured concentration within $\pm 10\%$ of certified concentration	(1) Repeat zero span calibration (2) Repeat control sample analysis
		(4) Drift check	Daily, at conclusion of testing	Methane	Drift value $\leq 20\%$ of the input value	(1) Flag day's data as questionable (2) Repair or discontinue use of analyzer
	PID	(1) Multipoint calibration (zero plus three upscale concentrations)	At start of program	Benzene or other aromatic compound	Correlation coefficient $\geq 0.995$	Repeat multipoint calibration after checking calibration dilution system
	PID	(2) Zero/span calibration	Daily	Benzene or other aromatic compound	Response factor agreement within $\pm 20\%$ of mean RF for multipoint calibration	(1) Repeat zero/span calibration (2) If still unacceptable, repeat multipoint calibration
		(3) Control sample analysis	Daily, prior to testing	Benzene or other aromatic compound	Measured concentration within $\pm 10\%$ of certified concentration	(1) Repeat zero/span calibration (2) Repeat control sample analysis
		(4) Drift check	Daily, at conclusion of testing	Benzene or other aromatic compound	Drift $\leq 20\%$ of the input value	(1) Flag day's data as questionable (2) Repair or discontinue use of analyzer
	FID	(1) Multipoint calibration (zero plus three upscale concentrations)	At start of program	Benzene or toluene	Correlation coefficient $\geq 0.995$	Repeat multipoint calibration after checking calibration dilution system
		(2) Zero/span calibration	Daily	UHP air or N <sub>2</sub> /methane	Response factor agreement within $\pm 20\%$ of mean RF for multipoint calibration	(1) Repeat zero/span calibration (2) If still unacceptable, repeat multipoint calibration
		(3) Control sample analysis	Daily, prior to testing	Benzene	Measured concentration within $\pm 10\%$ of certified concentration	(1) Repeat zero/span calibration (2) Repeat control sample analysis
		(4) Drift check	Daily, at conclusion of testing	Benzene	Drift $\leq 20\%$ of the input value	(1) Flag day's data as questionable (2) Repair or discontinue use of analyzer
		(5) Retention time checks	Daily	Benzene or toluene	None	None
		(6) Analytical blanks	Daily	UHP air or N <sub>2</sub>	Measured concentration $\leq 5\%$ of the instrument span value	Clean/replace system components until acceptable blank can be obtained
		(7) Sampling system blanks	Daily, plus after very high samples	Sample gas	Measured concentration $\leq 5\%$ of the instrument span value	Clean/replace system components until acceptable blank can be obtained
		(8) Duplicate samples	10 % of sampling points, minimum	Sample gas	None; provides a measure of total sampling variability	None
		(9) Control point samples	After every ten samples or once per day, whichever is greater	Sample gas	None; provides a measure of temporal variability	None
		(10) Background samples	One sample per day	Sample gas	None; provides a measure of background concentration	None
	PID	(1) Multipoint calibration (zero plus three upscale concentrations)	At start of program	Benzene or toluene	Correlation coefficient $\geq 0.995$	Repeat multipoint calibration after checking calibration dilution system
		(2) Zero span calibration	Daily	UHP air or N <sub>2</sub> /methane	Response factor agreement within $\pm 20\%$ of mean RF for multipoint calibration	(1) Repeat zero/span calibration (2) If still unacceptable, repeat multipoint calibration







TABLE 4 Continued

Type of Instrument	Detector Type	Type of Calibration/QC Test	Frequency	Gas Standard(s)	Acceptance Criteria	Corrective Action
	PID	(3) Control sample analysis	Daily, prior to testing	Benzene	Measured concentration within $\pm 10\%$ of certified concentration	(1) Repeat zero/span calibration (2) Repeat control sample analysis
		(4) Drift check	Daily, at conclusion of testing	Benzene	Drift $\leq 20\%$ of the input value	(1) Flag day's data as questionable (2) Repair or discontinue use of analyzer
		(5) Retention time checks	Daily	Benzene or toluene	None	None
		(6) Analytical blanks	Daily	UHP air or N <sub>2</sub>	Measured concentration $\leq 5\%$ of the instrument span value	Clean/replace system components until acceptable blank can be obtained
		(7) Sampling system blanks	Daily (plus after very high samples)	Sample gas	Measured concentration $\leq 5\%$ of the instrument span value	Clean/replace system components until acceptable blank can be obtained
		(8) Duplicate samples	10 % of sampling points, minimum	Sample gas	None; provides a measure of total sampling variability	None
		(9) Control point samples	After every ten samples or once per day, whichever is greater	Sample gas	None; provides a measure of temporal variability	None
		(10) Background samples	One sample per day	Sample gas	None; provides a measure of background concentration	None
	FID	(1) Multipoint calibration (zero plus three upscale concentrations)	1 per month	Propane/hexane	Correlation coefficient $\geq 0.995$	Repeat linearity check
		(2) Single point calibration check	Daily, prior to sample analyses	Propane/hexane	Response factor agreement within $\pm 20\%$ of most recent average RFs for multipoint calibration	Repeat single point calibration
Off-site Gas Chromatograph		(3) Retention time check	Daily, prior to sample analyses	Multicomponent standard	Agreement with preestablished relative retention times	Adjust GC conditions and repeat RT check
	FID	(4) Control sample analysis	Daily, prior to sample analyses	Sample gas	(1) Correct identification of 90 % of components (2) For 90 % of components, measured concentrations within $\pm 30\%$ of actual concentrations	Repeat control sample analysis
		(5) Duplicate analyses	Minimum 10 % of samples (all duplicate samples will be analyzed in duplicate)	Sample gas	CV $\leq 20\%$ for ten major sample components	Repeat sample analysis
		(6) Blank analysis	Daily, prior to sample analysis	UHP air or N <sub>2</sub>	Total $\leq 20$ ppbv-C	(1) Clean system (2) Repeat blank analysis
	PID	(1) Multipoint calibration (zero plus three upscale concentrations)	1 per month	Propane/hexane	Correlation coefficient $\geq 0.995$	Repeat linearity check
	PID	(2) Single point calibration check	Daily, prior to sample analyses	Propane/hexane	Response factor agreement within $\pm 20\%$ of most recent average RFs for multipoint calibrations	Repeat single point calibration
		(3) Retention time check	Daily, prior to sample analyses	Multicomponent standard	Agreement with preestablished relative retention times	Adjust QC conditions and repeat RT check
		(4) Control sample analysis	Daily, prior to control sample analyses	Sample gas	(1) Correct identification of 90 % of components (2) For 90 % of components, measured concentrations within $\pm 30\%$ of actual concentrations	Repeat control sample analysis
		(5) Duplicate analyses	Minimum 10 % of samples. (Duplicate samples analyzed in duplicate)	Sample gas	CV $\leq 20\%$ for ten major sample components	Repeat sample analysis
	PID	(6) Blank analysis	Daily, prior to sample analysis	UHP air or N <sub>2</sub>	Total $\leq 20$ ppbv-C	(1) Clean system (2) Repeat blank analysis







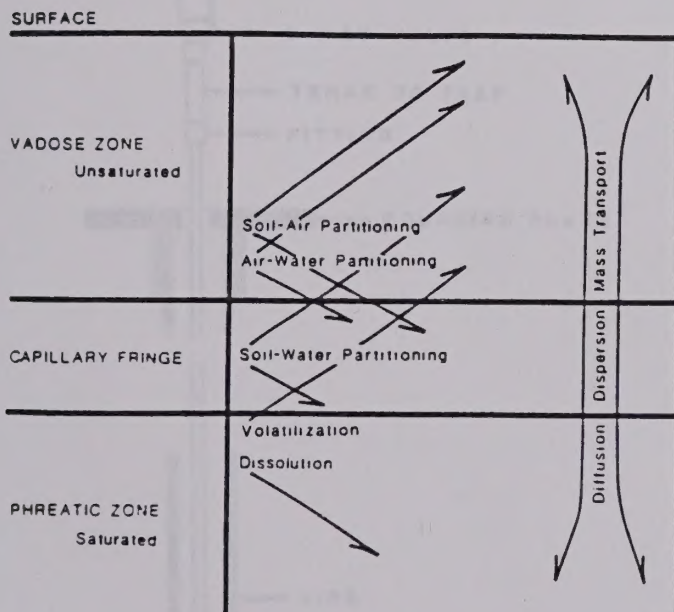
TABLE 4 Continued

Type of Instrument	Detector Type	Type of Calibration/QC Test	Frequency	Gas Standard(s)	Acceptance Criteria	Corrective Action
ECD		(1) Quantitative standard	Daily, prior to sample analysis	Multicomponent standard	Response factor agreement within $\pm 30\%$ of three day rolling mean RFs for all components	Repeat calibration
		(2) Retention time check	Daily, prior to sample analyses	Multicomponent standard	None; will provide basis for comparison of FID/PID results to ECD results	None
		(3) Control sample analysis	Daily, prior to sample analyses	Sample gas	(1) Correct identification of all components (2) For 90 % of components, measured concentrations within $\pm 30\%$ of actual concentrations	Repeat control sample analysis
ECD		(4) Duplicate analyses	Minimum of 10 % of samples (all duplicate samples analyzed in duplicate)	Sample gas	CV $\leq 20\%$ for ten major sample components	Repeat sample analysis
		(5) Blank analysis	Daily, prior to sample analyses	UHP air or N <sub>2</sub>	Total $\leq 20$ ppbv-C	(1) Clean system (2) Repeat blank analysis

<sup>A</sup> See Ref (10).

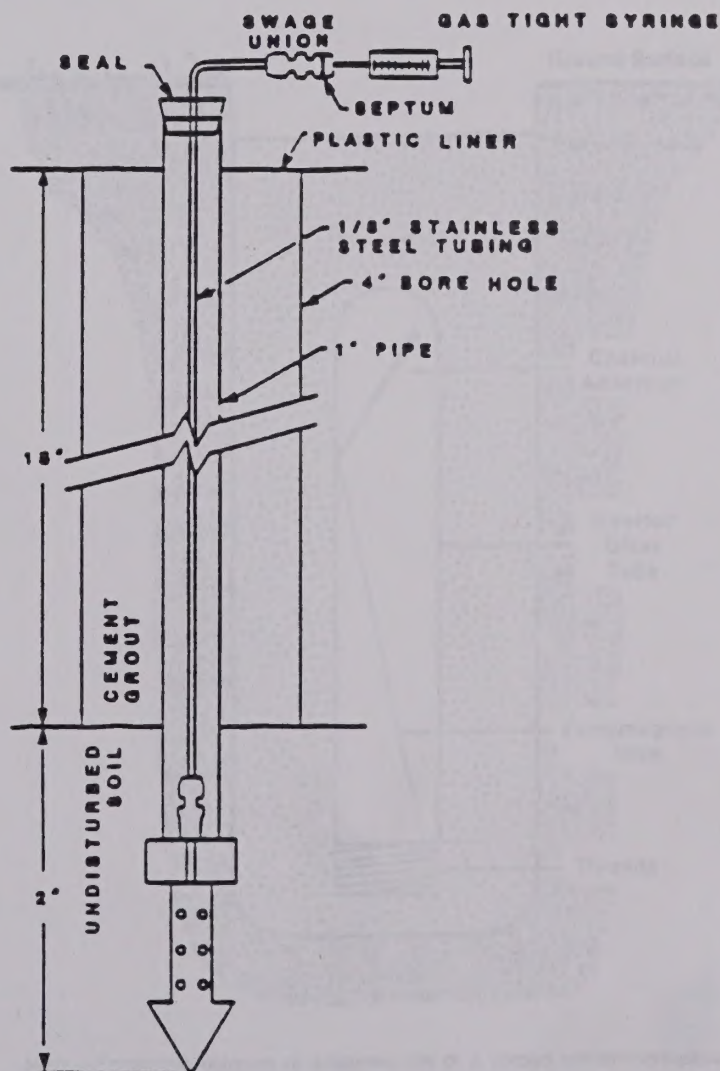
## APPENDIX

### (Nonmandatory Information)



NOTE—The processes indicated by the soil gas monitoring method are partitioning, migration, emplacement and degradation. Partitioning represents a group of processes which control contaminant movement from one physical phase to another, these phases being liquid, free vapor, occluded vapor, solute and sorbed. Migration refers to contaminant movement over distance with any vertical, horizontal or temporal component. Emplacement refers to establishment of contaminant residence in any phase within any residence opportunity. Degradation is the process whereby contaminants are attenuated by oxidation or reduction in the vadose zone, either through biogenic or abiotic processes. Soil gas monitoring measures the result of the interaction of these processes in a dynamic equilibrium.

FIG. X1.1 Arena of Soil Gas Monitoring



NOTE—Ground probe designed and used by Crow et al., 1985, from Ref (10).

FIG. X1.2 Example of Whole-Air Active Sampling System



TABLE 1

Test No.	Test Date	Test Location	Test Description	Test Results	Test Comments
100	10/1/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
101	10/2/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
102	10/3/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
103	10/4/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
104	10/5/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
105	10/6/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
106	10/7/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
107	10/8/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
108	10/9/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
109	10/10/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
110	10/11/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
111	10/12/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
112	10/13/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
113	10/14/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
114	10/15/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
115	10/16/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
116	10/17/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
117	10/18/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
118	10/19/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
119	10/20/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
120	10/21/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
121	10/22/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
122	10/23/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
123	10/24/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
124	10/25/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
125	10/26/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
126	10/27/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
127	10/28/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
128	10/29/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
129	10/30/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep
130	10/31/50	100 ft. deep	100 ft. deep	100 ft. deep	100 ft. deep

APPENDIX

(Continuation of Table 1)

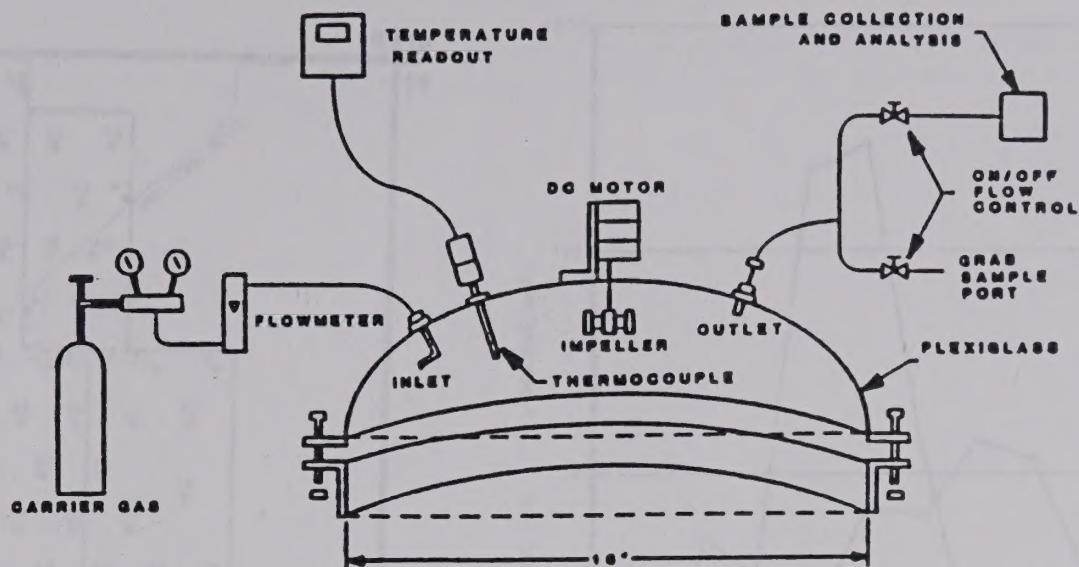


The diagram shows a vertical cross-section of a well or borehole. The shaft is shown running from the surface down to the water table. The water table is indicated by a dashed line. The diagram is oriented vertically with the shaft running from top to bottom. The layers and components are labeled as follows: WATER LEVEL, WATER TABLE, SHAFT, and WATER TABLE. The diagram is oriented vertically with the shaft running from top to bottom.

FIG. 1. Example of a well or borehole. The diagram shows a vertical cross-section of a well or borehole. The shaft is shown running from the surface down to the water table. The water table is indicated by a dashed line. The diagram is oriented vertically with the shaft running from top to bottom. The layers and components are labeled as follows: WATER LEVEL, WATER TABLE, SHAFT, and WATER TABLE. The diagram is oriented vertically with the shaft running from top to bottom.

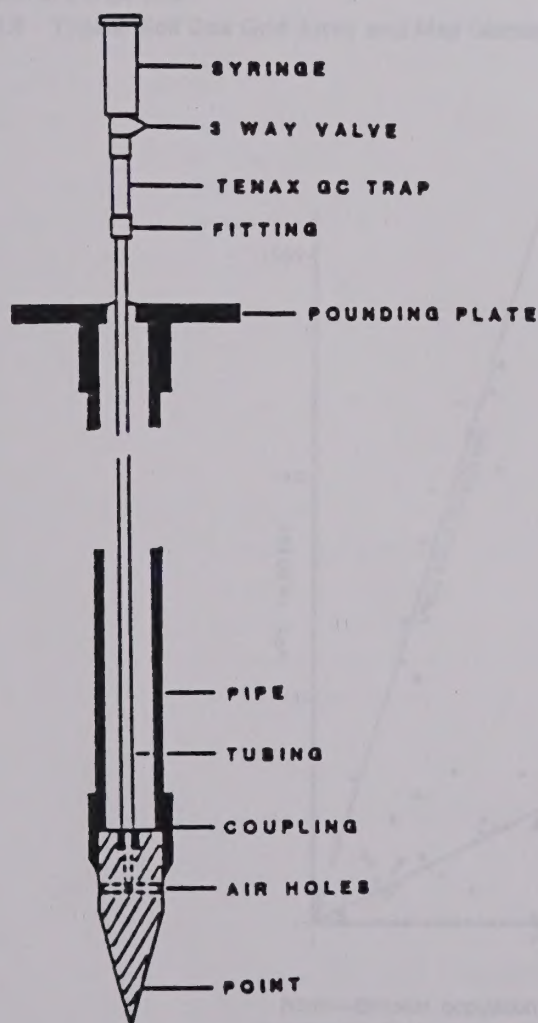
FIG. 2. Example of a well or borehole. The diagram shows a horizontal cross-section of a well or borehole. The shaft is shown running from the surface down to the water table. The water table is indicated by a dashed line. The diagram is oriented horizontally with the shaft running from left to right. The layers and components are labeled as follows: WATER LEVEL, WATER TABLE, SHAFT, and WATER TABLE. The diagram is oriented horizontally with the shaft running from left to right.





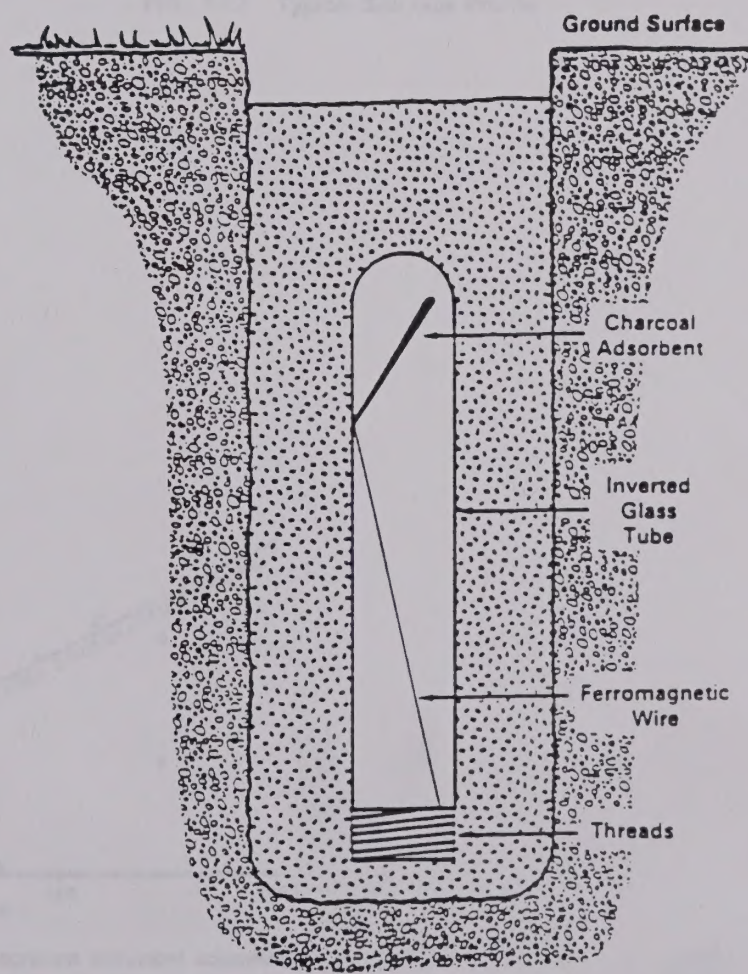
NOTE—Surface flux chamber and peripheral equipment after Eklund et al., 1984, from Ref (10).

FIG. X1.3 Example of Whole-Air Passive Sampling System



NOTE—Ground probe design used by Swallow and Gachwend, 1983, from Ref (10).

FIG. X1.4 Example of Sorbed Contaminant-Active System



NOTE—Schematic diagram of emplacement of a sorbed contaminant-passive system (10).

FIG. X1.5 Example of Sorbed Contaminant-Passive System



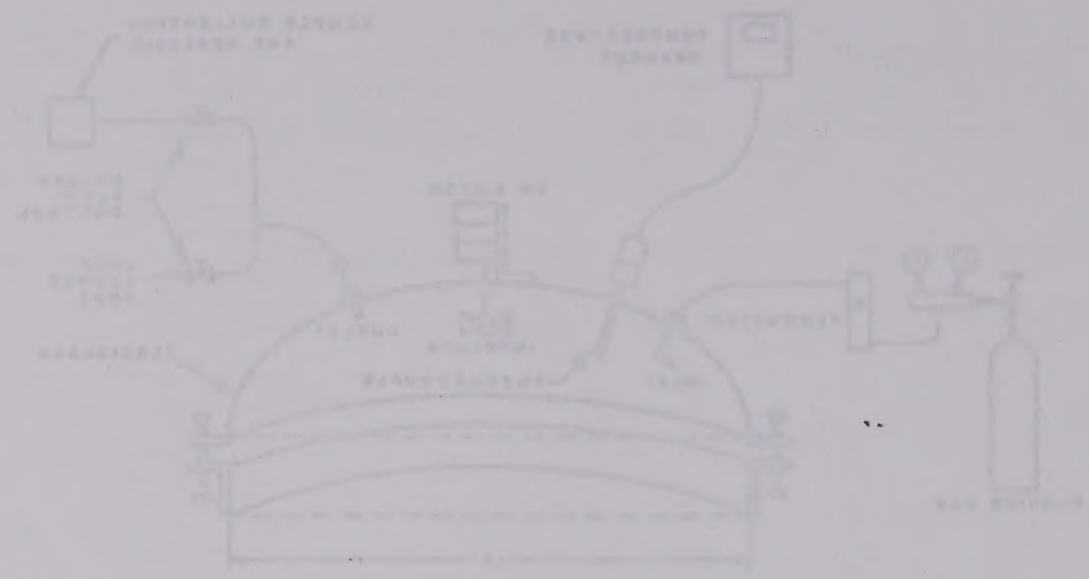


FIG. 1. Schematic diagram of the mechanical system.

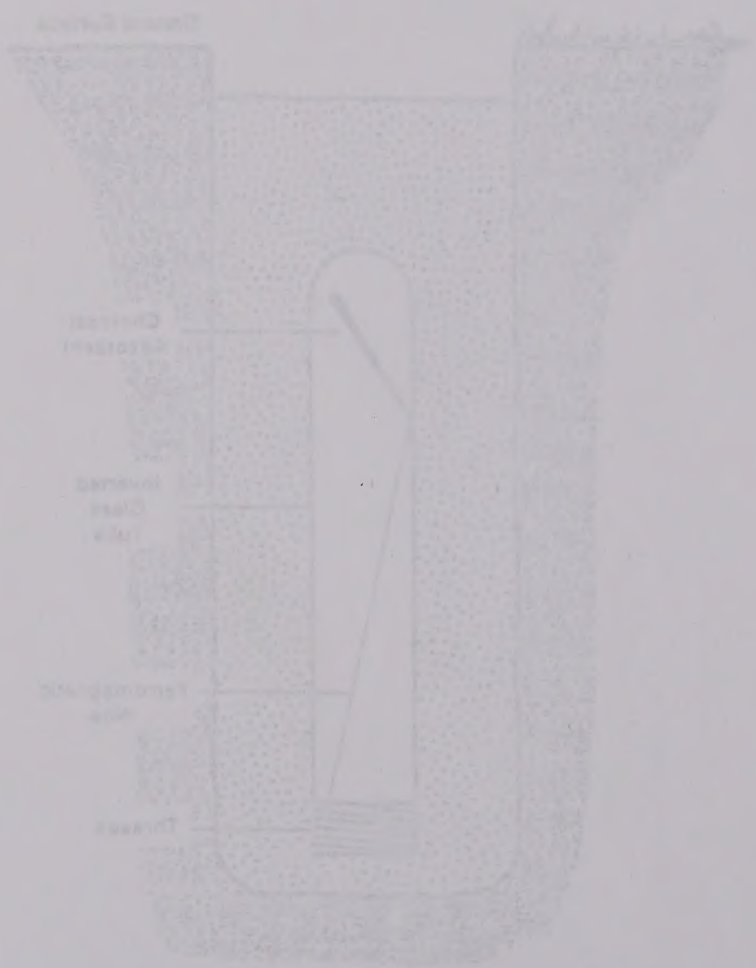
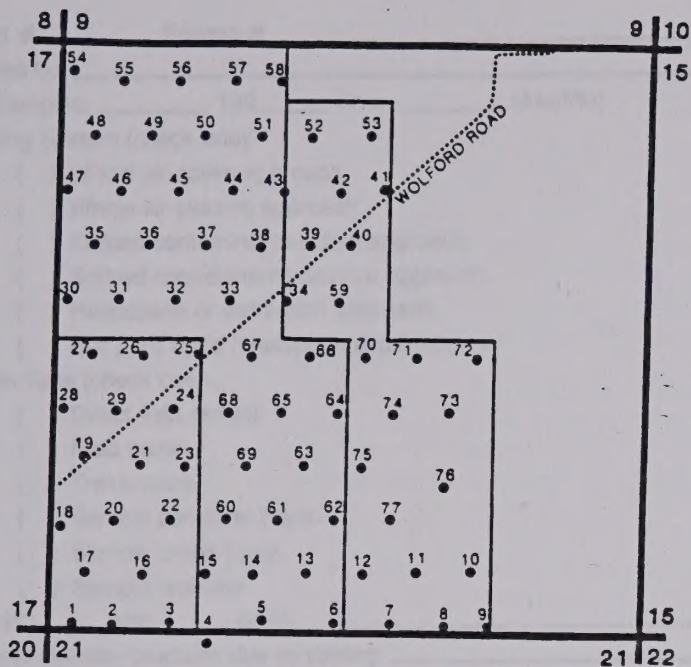


FIG. 2. Cross-section of the container.



FIG. 3. Detailed cross-section of the vertical assembly.

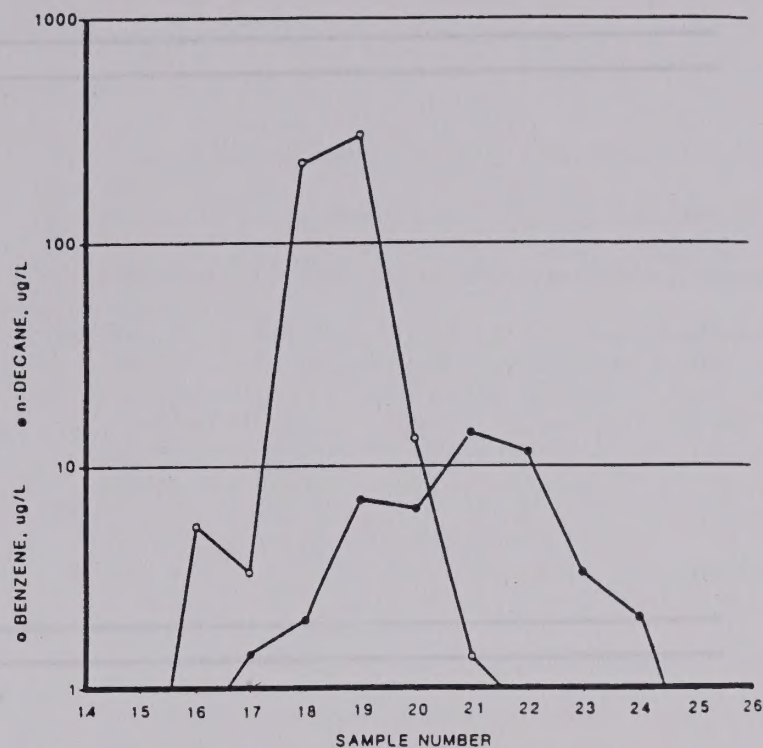




MAP SCALE: 1" = 1,000'

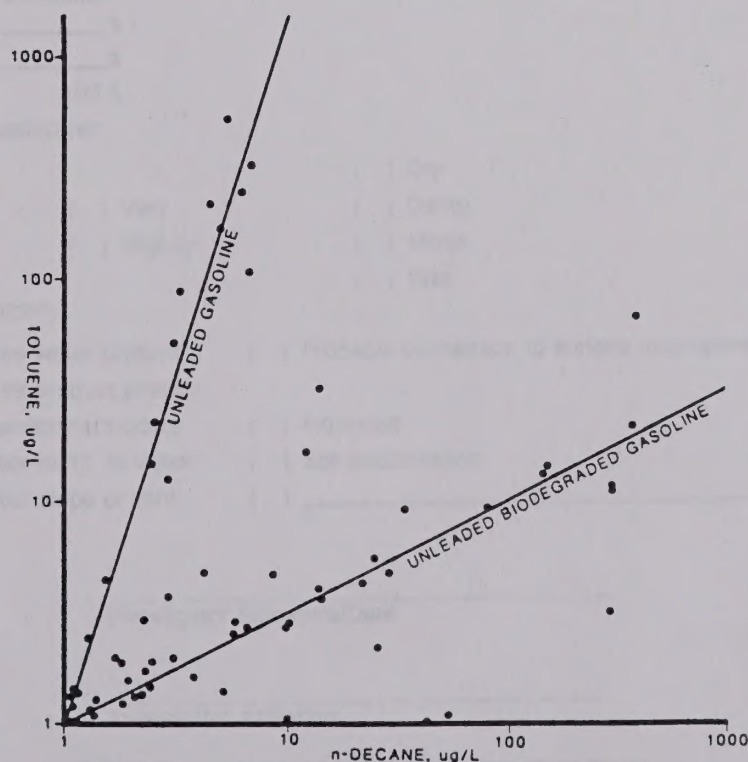
NOTE—In any application, soil gas monitoring can be performed over a wide range of spatial designs, including soil gas sampling in grid patterns at a single depth or multiple depths. This example illustrates a staggered grid pattern of samples recovered at a single depth.

FIG. X1.6 Typical Soil Gas Grid Array and Map Display



NOTE—Soil gas data from survey profiles displayed on an X - Y plot is an effective aid to data interpretation. This display is useful to examine the overall context for soil gas measurement data potentially indicating contamination. If the profile is displayed as a cross section through a grid pattern or as a linear array of sample points, the profile display can illustrate spatially significant groupings of data subpopulations.

FIG. X1.7 Typical Soil Gas Profile



NOTE—Bimodal populations of data that represent coincident contaminant occurrences (for example, soil gas contaminant vapors sourced from converging plumes of two different fuels or mixtures of gasoline and biodegraded gasoline) can be defined using compositional analyses. One technique of compositional analysis is cross-plotting as shown.

FIG. X1.8 Soil Gas Compositional Analysis by Cross Plot







Project # \_\_\_\_\_ Sample # \_\_\_\_\_

Sampled by: \_\_\_\_\_

Date Sampled: \_\_\_\_\_, 199\_\_\_\_ Time: \_\_\_\_\_ (AM/PM)

Sampling System (check one):

( ) Whole air-active approach

( ) Whole air-passive approach

( ) Sorbed contaminants-active approach

( ) Sorbed contaminants-passive approach

( ) Headspace or extraction approach

( ) Soil pore liquid headspace approach

Sample Type (check one):

( ) Direct field sample

( ) Field blank

( ) Travel blank

( ) Sample container blank

( ) Sample probe blank

( ) Sample replicate

Spiked? \_\_\_\_\_ with \_\_\_\_\_ cc of \_\_\_\_\_

Potential reaction products due to spiking: \_\_\_\_\_

System purge volume: \_\_\_\_\_ Volumes purged: \_\_\_\_\_ Sample volume: \_\_\_\_\_

Sorbent Device: Installed \_\_\_\_\_ (AM/PM), \_\_\_\_\_, 199\_\_\_\_

Recovered \_\_\_\_\_ (AM/PM), \_\_\_\_\_, 199\_\_\_\_

Sample container type: \_\_\_\_\_ Sample container # \_\_\_\_\_

Integral analyzer: \_\_\_\_\_ Detector: \_\_\_\_\_

Analyzer response: \_\_\_\_\_ (units) \_\_\_\_\_

Surface conditions (pavement, wet, frost, etc.) \_\_\_\_\_

Sample depth: \_\_\_\_\_ Sampling rate: \_\_\_\_\_

Sample horizon data-visual estimates:

Vadose zone make-up: ( ) Native soil+rock ( ) Fill ( ) Rock

Soil composition: Clay, \_\_\_\_\_%

Soil organic matter, \_\_\_\_\_%

Fine granular material, \_\_\_\_\_%

Coarse granular material, \_\_\_\_\_%

100 %

Moisture content of sampling horizon (qualitative):

( ) Dry

( ) Very

( ) Slightly

( ) Damp

( ) Moist

( ) Wet

Other characteristics of the sampling horizon:

( ) Free water present ( ) Probable connection to surface macropores

( ) Free product present

( ) Contaminant odors ( ) Indurated

( ) Poor perm. to vapor ( ) Soil discoloration

( ) Near slope or vent ( ) \_\_\_\_\_

Investigator Signature/Date \_\_\_\_\_

Investigator Affiliation \_\_\_\_\_

**FIG. X1.9 Suggested Soil Gas Sample Data Sheet**







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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.









## Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock<sup>1</sup>

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This test method covers the laboratory determination of the water (moisture) content of soil, rock, and similar materials by mass. For simplicity, the word “material” hereinafter also refers to either soil or rock, whichever is most applicable.

1.2 The water content of a material is defined by this standard as the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of material to the mass of the solid material.

1.3 The term “solid particles” as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, and the like) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate or other compounds having significant amounts of hydrated water) may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidities, forming a compound (calcium sulfate hemihydrate) which is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum, or to reduce decomposition in highly organic soils, it may be desirable to dry these materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from standard water content determined at the standard drying temperature.

NOTE 1—Test Methods D 2974 provides an alternate procedure for determining water content of peat materials.

1.4 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids which includes the previously soluble solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the

specimen, or a qualified definition of water content must be used.

1.5 This test method requires several hours for proper drying of the water content specimen. Test Method D 4643 provides for drying of the test specimen in a microwave oven which is a shorter process.

1.6 This standard requires the drying of material in an oven at high temperatures. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

1.7 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
- D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils<sup>2</sup>
- D 4220 Practice for Preserving and Transporting Soil Samples<sup>2</sup>
- D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils<sup>2</sup>
- D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method<sup>2</sup>
- D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing<sup>2</sup>
- E 145 Specification for Gravity-Convection And Forced-Ventilation Ovens<sup>3</sup>

### 3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

#### 3.2 Description of Term Specific to This Standard:

3.2.1 *water content* (of a material)—the ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles in that material, expressed as a percentage.

<sup>1</sup> This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 04.08.

<sup>3</sup> Annual Book of ASTM Standards, Vol 14.02.







## 4. Summary of Test Method

4.1 A test specimen is dried in an oven to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

## 5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D 4318, is used to express its relative consistency or liquidity index.

## 6. Apparatus

6.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of  $110 \pm 5^\circ\text{C}$  throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification D 4753 and this Section. A Class GP1 balance of 0.01g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1g readability is required for specimens having a mass over 200 g.

6.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used. One container is needed for each water content determination.

NOTE 2—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium phosphate. It is preferable to use a desiccant which changes color to indicate it needs reconstitution. See Section 10.5.

NOTE 3—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus*, gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quartering cloth, sample splitters, etc., as required.

## 7. Samples

7.1 Samples shall be preserved and transported in accordance with Practice 4220 Groups B, C, or D soils. Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and  $30^\circ\text{C}$  and in an area that prevents direct contact with

sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

## 8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given before shall apply.

8.2 The minimum mass of moist material selected to be representative of the total sample, if the total sample is not tested by this method, shall be in accordance with the following:

Maximum particle size (100 % passing)	Standard Sieve Size	Recommended minimum mass of moist test specimen for water content reported to $\pm 0.1\%$	Recommended minimum mass of moist test specimen for water content reported to $\pm 1\%$
2 mm or less	No. 10	20 g	20 g*
4.75 mm	No. 4	100 g	20 g*
9.5 mm	3/8-in.	500 g	50 g
19.0 mm	3/4-in.	2.5 kg	250 g
37.5 mm	1 1/2 in.	10 kg	1 kg
75.0 mm	3-in.	50 kg	5 kg

NOTE—\*To be representative not less than 20 g shall be used.

8.2.1 If the total sample is used it does not have to meet the minimum mass requirements provided in the table above. The report shall indicate that the entire sample was used.

8.3 Using a test specimen smaller than the minimum indicated in 8.2 requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted in the report of results.

8.4 When working with a small (less than 200g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted in the report of the results.

8.5 For those samples consisting entirely of intact rock, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles, depending on the sample's size, the container and balance being used and to facilitate drying to constant mass, see Section 10.4.

## 9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, and the likes.)

9.2 For disturbed samples such as trimmings, bag samples, and the like, obtain the test specimen by one of the









# Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>1</sup>

This standard is issued under the fixed designation D 2488; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.*

## 1. Scope

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D 2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D 2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils (disturbed and undisturbed).

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (See Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific precautionary statements see Section 8.*

1.5 The values stated in inch-pound units are to be regarded as the standard.

## 2. Referenced Documents

### 2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>

D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils<sup>2</sup>

D 1587 Practice for Thin-Walled Tube Sampling of Soils<sup>2</sup>

D 2113 Practice for Diamond Core Drilling for Site Investigation<sup>2</sup>

D 2487 Test Method for Classification of Soils for Engineering Purposes<sup>2</sup>

D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)<sup>2</sup>

## 3. Terminology

### 3.1 Definitions:

3.1.1 Except as listed below, all definitions are in accordance with Terminology D 653.

NOTE 2—For particles retained on a 3-in. (75-mm) US standard sieve, the following definitions are suggested:

*Cobbles*—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve, and

*Boulders*—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1.2 *clay*—soil passing a No. 200 (75- $\mu$ m) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 3 of Test Method D 2487).

3.1.1.3 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

*coarse*—passes a 3-in. (75-mm) sieve and is retained on a 3/4-in. (19-mm) sieve.

*fine*—passes a 3/4-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

3.1.1.4 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.1.5 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.1.6 *peat*—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.1.7 *sand*—particles of rock that will pass a No. 4

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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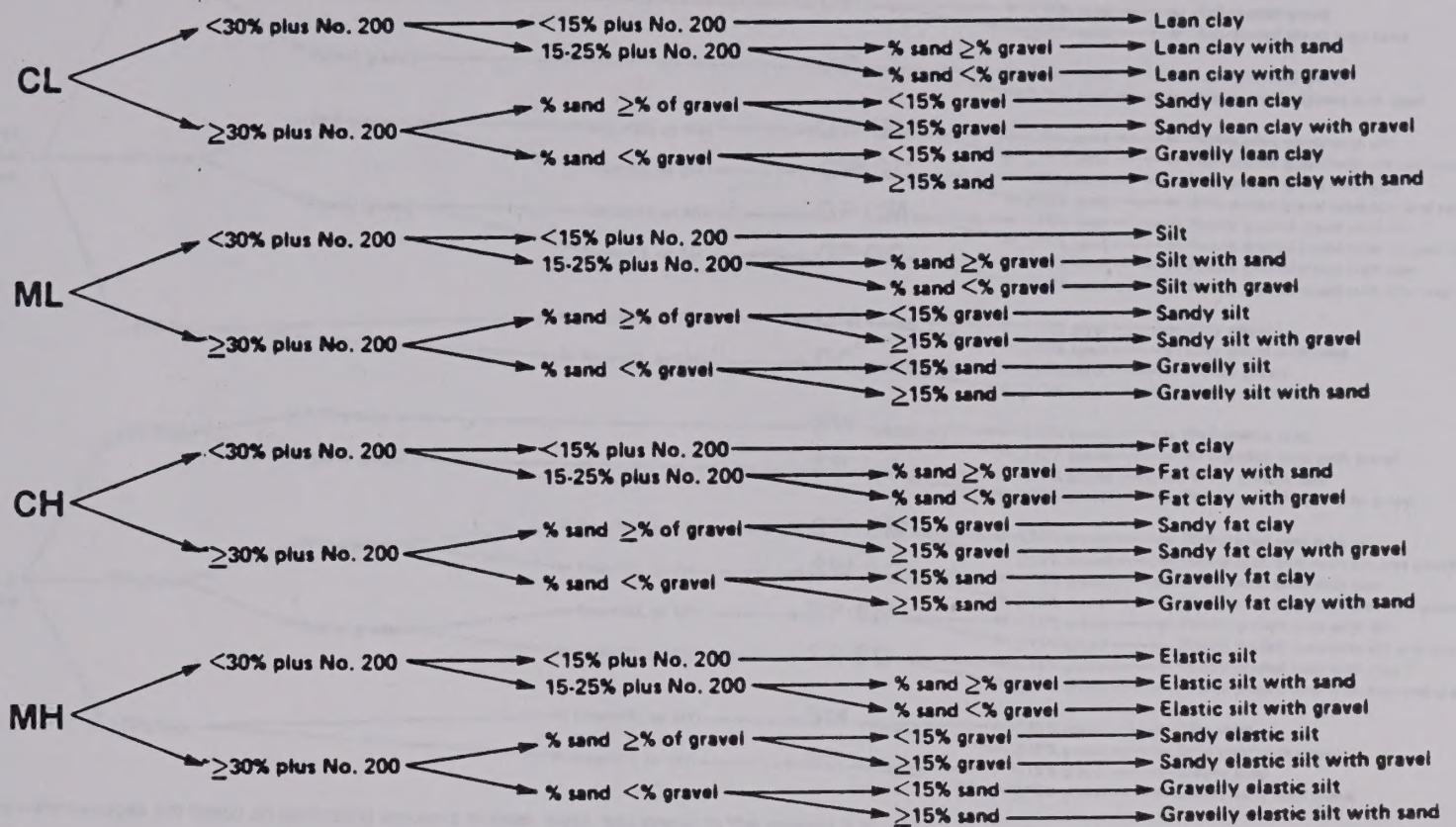






GROUP SYMBOL

GROUP NAME



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)

(4.75-mm) sieve and be retained on a No. 200 (75-μm) sieve with the following subdivisions:

*coarse*—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

*medium*—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-μm) sieve.

*fine*—passes a No. 40 (425-μm) sieve and is retained on a No. 200 (75-μm) sieve.

3.1.1.8 *silt*—soil passing a No. 200 (75-μm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the “A” line (see Fig. 3 of Test Method D 2487).

#### 4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

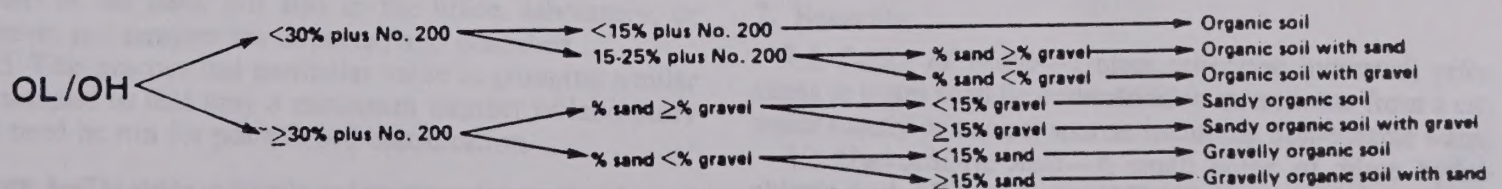
4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Figs. 1a and 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols*.

*Dual Symbol*—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D 2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or

GROUP SYMBOL

GROUP NAME



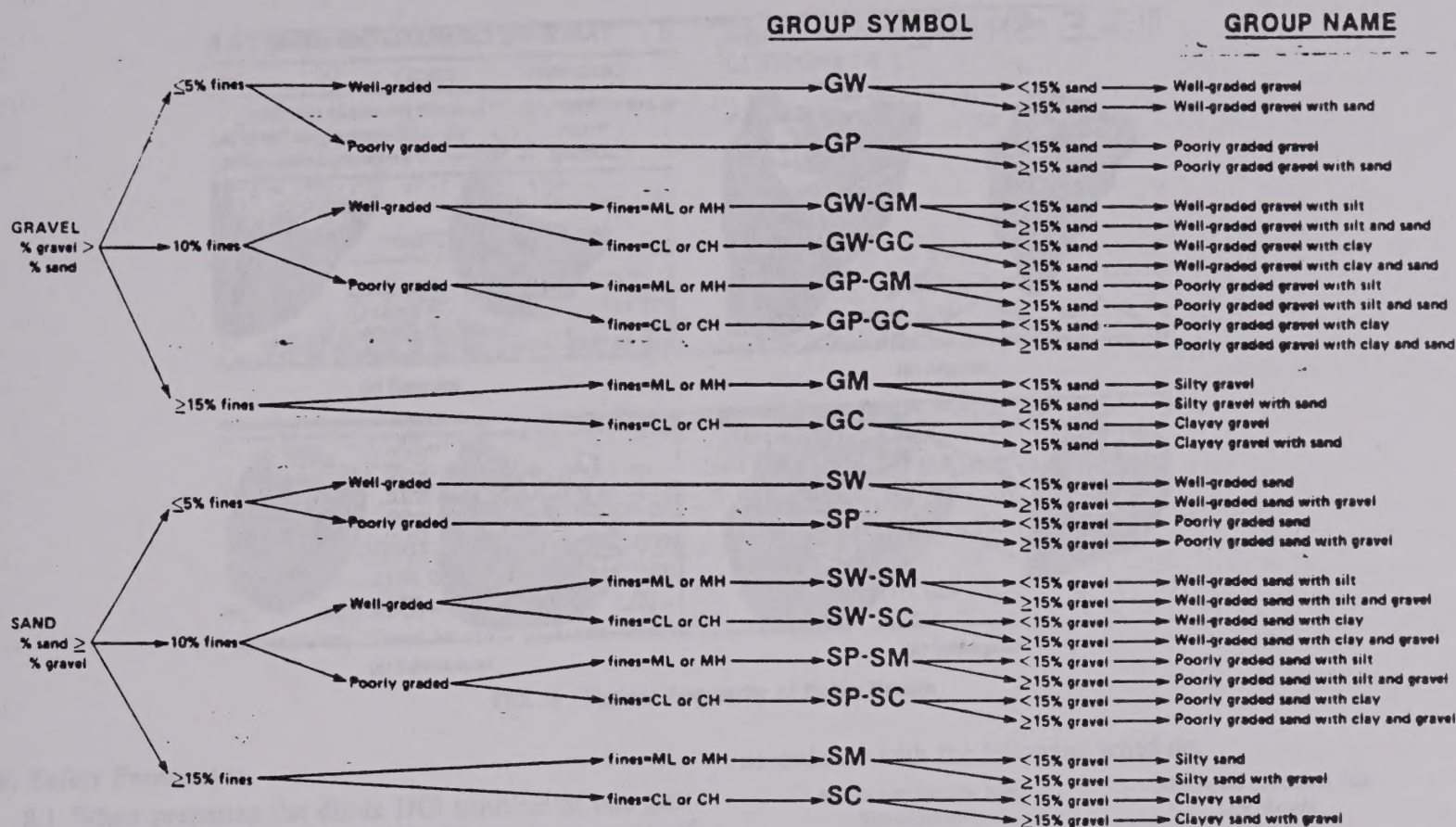
NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)









NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

**Borderline Symbol**—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

## 5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D 2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D 2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D 2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test

results for typical soils of each type with their visual and manual characteristics.

5.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the procedures in this practice for every sample. Soils which appear to be similar can be grouped together; one sample completely described and identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

5.7 This practice may be used in combination with Practice D 4083 when working with frozen soils.

## 6. Apparatus

6.1 *Required Apparatus:*

6.1.1 *Pocket Knife or Small Spatula.*

6.2 *Useful Auxiliary Apparatus:*

6.2.1 *Small Test Tube and Stopper (or jar with a lid).*

6.2.2 *Small Hand Lens.*

## 7. Reagents

7.1 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 *Hydrochloric Acid*—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 N) to three parts water (This reagent is optional for use with this practice). See Section 8.









FIG. 3 Typical Angularity of Bulky Grains

## 8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 N) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 Caution—Do not add water to acid.

## 9. Sampling

9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 5—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D 1452, D 1587, or D 2113, or Method D 1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 6—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in

accordance with the following schedule:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.5 lb)
9.5 mm (3/8 in.)	200 g (0.5 lb)
19.0 mm (3/4 in.)	1.0 kg (2.2 lb)
38.1 mm (1 1/2 in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 7—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceding schedule.

9.4 If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark.

## 10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

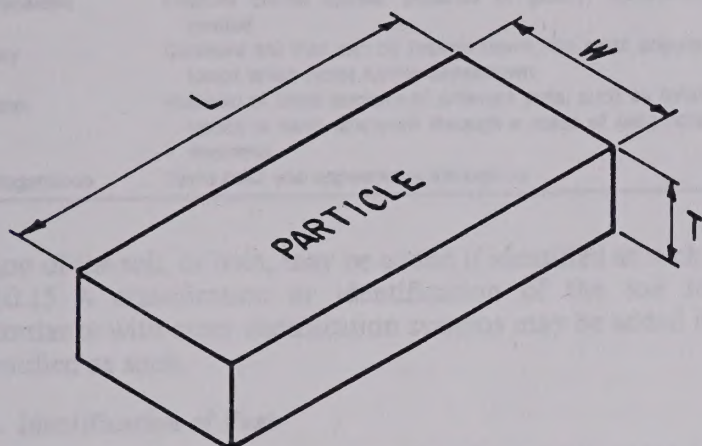






## PARTICLE SHAPE

W = WIDTH  
T = THICKNESS  
L = LENGTH



FLAT:  $W/T > 3$   
ELONGATED:  $L/W > 3$   
FLAT AND ELONGATED:  
-meets both criteria

FIG. 4 Criteria for Particle Shape

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the criteria in Table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about 1/4 in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

10.7 *Consistency*—For intact fine-grained soil, describe the consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in 3.1.6. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1 1/2 in. (will pass a 1 1/2-in. square opening but not a 3/4-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under a hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation.

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure







TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

tation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

### 11. Identification of Peat

11.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

### 12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 8—Since the percentages of the particle-size distribution in Test Method D 2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 9—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

### 13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more

fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

### 14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

#### 14.2 Dry Strength:

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 10—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accordance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

#### 14.3 Dilatancy:

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface







TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

#### 14.4 Toughness:

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about 1/8 in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about 1/8 in. The thread will crumble at a diameter of 1/8 in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

#### 14.7 Identification of Inorganic Fine-Grained Soils:

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A 1/8-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 12).

NOTE 11—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D 2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing for proper identification.

#### 14.8 Identification of Organic Fine-Grained Soils:

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 12—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

14.9 If the soil is estimated to have 15 to 25 % sand or gravel, or both, the words “with sand” or “with gravel” (whichever is more predominant) shall be added to the group name. For example: “lean clay with sand, CL” or “silt with gravel, ML” (see Figs. 1a and 1b). If the percentage of sand is equal to the percentage of gravel, use “with sand.”

14.10 If the soil is estimated to have 30 % or more sand or gravel, or both, the words “sandy” or “gravelly” shall be added to the group name. Add the word “sandy” if there appears to be more sand than gravel. Add the word “gravelly” if there appears to be more gravel than sand. For example: “sandy lean clay, CL”, “gravelly fat clay, CH”, or “sandy silt, ML” (see Figs. 1a and 1b). If the percentage of sand is equal to the percent of gravel, use “sandy.”

#### 15. Procedure for Identifying Coarse-Grained Soils (Contains less than 50 % fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High







15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded sand with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

## 16. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 13—Example: *Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak

TABLE 13 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:
  - Gravel—fine, coarse
  - Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong
- For intact samples:
  18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
  19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
  20. Cementation: weak, moderate, strong
  21. Local name
  22. Geologic interpretation
  23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

NOTE 14—Other examples of soil descriptions and identification are given in Appendixes X1 and X2.

NOTE 15—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %

Few—5 to 10 %

Little—15 to 25 %

Some—30 to 45 %

Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D 2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

## 17. Precision and Bias

17.1 This practice provides qualitative information only; therefore, a precision and bias statement is not applicable.

## 18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification







## APPENDIXES

### (Nonmandatory Information)

#### X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 25 mm; no reaction with HCl (Note—Field sample size smaller than recommended).

*In-Place Conditions*—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray;

in-place density 106 lb/ft<sup>3</sup>; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 75 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—About 75 % fine to coarse, hard, subrounded to subangular gravel; about 15 % fine, hard, subrounded to subangular sand; about 10 % silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 18 in. (450 mm).

#### X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, AND THE LIKE

X2.1 The identification procedure may be used as a descriptive system applied to materials that exist in-situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how group names and symbols can be incorporated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to

100-mm) pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 h, material identified as "Sandy Lean Clay (CL)"; about 60 % fines with medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium, hard sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—About 60 % gravel-size broken shells; about 30 % sand and sand-size shell pieces; about 10 % fines; "Poorly Graded Gravel with Sand (GP)."

X2.4.4 *Crushed Rock*—Processed from gravel and cobbles in Pit No. 7; "Poorly Graded Gravel (GP)"; about 90 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

#### X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two

possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example: SC/CL or CL/CH.

X3.1.1 A borderline symbol may be used when the







percentage of fines is estimated to be between 45 and 55 %. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML or CL/SC.

X3.1.2 A borderline symbol may be used when the percentage of sand and the percentage of gravel are estimated to be about the same. For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

X3.1.5 A borderline symbol may be used when a fine-

grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH lean to fat clay

ML/CL clayey silt

CL/ML silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

#### X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method*—The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 s. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method*—Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size

present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

#### X5. RATIONALE

X5.1 This practice was significantly revised in the D 2488 – 84 version from the previous version D 2488 – 69 (1975). The revisions are documented in the literature.<sup>3</sup>

X5.2 Changes in this version from the previous version include rewording of 1.2.3 to say (disturbed and undisturbed), the addition of 5.7 to refer to the practice for describing frozen soils, and the addition of Appendix X5 on Rationale.

<sup>3</sup> Howard, A. K. "The Revised ASTM Standard on the Description and Identification of Soils (Visual-Manual Procedure)," *Geotechnical Testing Journal*, GTJODJ Vol. 10, No. 4, December 1987.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.







## Standard Practice for Ring-Lines Barrel Sampling of Soils<sup>1</sup>

This standard is issued under the fixed designation D 3550; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.*

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<sup>1</sup> NOTE—Section 8 was added editorially in November 1991.

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### 1. Scope

1.1 This practice covers a procedure for using a ring-lined barrel sampler to obtain representative samples of soil for identification purposes and other laboratory tests. In cases where it has been established that the quality of the sample is adequate, this practice provides shear and consolidation specimens that can be used directly in the test apparatus without prior trimming. Some types of soils may gain or lose significant shear strength or compressibility, or both, as a result of sampling. In cases like these, suitable comparison tests should be made to evaluate the effect of sample disturbance on shear strength and compressibility.

1.2 This practice is not intended to be used as a penetration test; however, the force required to achieve penetration or a blow count, when driving is necessary, is recommended as supplemental information.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:

- D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils<sup>2</sup>
- D 1587 Practice for Thin-Walled Tube Sampling of Soils<sup>2</sup>
- D 2113 Practice for Diamond Core Drilling for Site Investigation<sup>2</sup>
- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>2</sup>

### 3. Significance and Use

3.1 This practice is used where soil condition and resistance to advance of the sampler do not permit the use of a thin-wall tube (Practice D 1587) and where the formation does not require diamond coring (Practice D 2113).

### 4. Apparatus

4.1 *Drilling Equipment*—Any drilling equipment may be used that provides a reasonably clean hole before insertion of the sampler and that does not disturb the soil to be sampled. However, in no case shall a bottom-discharge bit be permitted. Side-discharge bits are permissible.

4.2 *Drive Weight Assembly*—Any drive weight assembly that will provide penetration in the range from 1 to 20 blows per foot (65 blows per metre) may be used. Whenever possible, soils are to be sampled by pushing instead of driving (see Section 5).

4.3 *Ring-Lined Barrel Sampling Assembly*—This shall consist of a shoe, sampler, and waste barrel, as shown in Fig. 1.

4.4 *Ring-Lined Sampler*—Test specimens shall be obtained using a suitable one piece or split sampling barrel lined on the inside with removable rings. These rings shall be thin-walled and shall conform to the size requirements of the particular laboratory test determinations employed. They shall fit snugly inside the sampler with no discernible free play in any direction. The sampler may be sectionalized to allow end-to-end make up of sections as necessary. Each section shall be designed so that addition or removal of sections will not loosen, permit movement, or otherwise adversely affect retention of the rings within the sampler. The sampler and rings shall be free of bumps, dents, scratches, rust, dirt, and corrosion.

NOTE 1—It is recommended that the sampler contain at least six rings in order to provide samples for a variety of tests.

4.5 *Waste Barrel*—A waste barrel that can be removed from the sampler in the field shall be provided to contain space for disturbed soil originally at the bottom of the hole. The length of the waste barrel shall be at least three times its interior diameter, and the inside diameter shall be the same, or slightly larger than, the inside diameter of the rings.

4.5.1 An attachment, check valve, and one or more vents is required. The design of these items is optional.

4.6 *Shoe*—The shoe shall be machined as shown in Fig. 1. The inside of the assembled shoe and ring-lined sampler shall be smooth, straight, and uniform. The thin-walled extension of the shoe shall be 2 to 4 in. (51 to 102 mm) in outside diameter and made of any materials of adequate strength and resistance to corrosion. The length of the thin-walled extension shall be equal to three times the diameter of its opening, but shall not exceed 8 in. (203 mm). The inside clearance ratio shall be between 0.5 and 3.0 %. (See Fig. 1 for

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

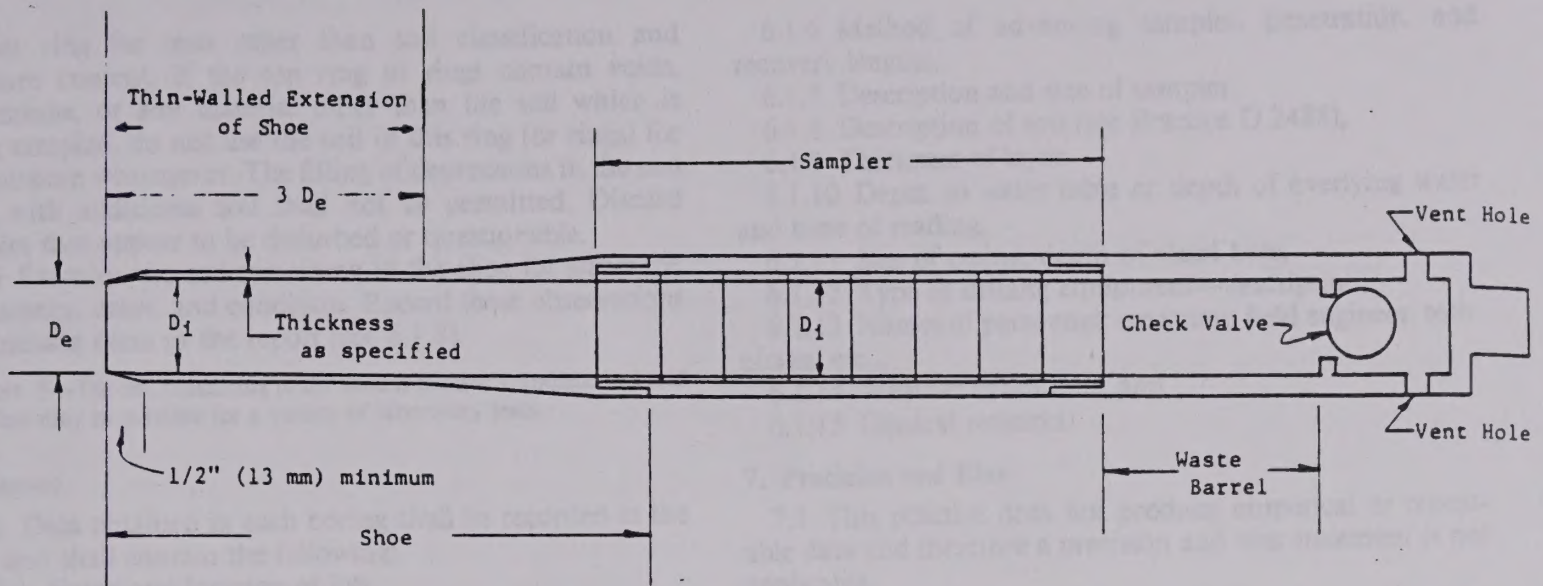
Current edition approved Jan. 27, 1984. Published April 1984. Originally published as D 3550 - 77. Last previous edition D 3550 - 77<sup>ε1</sup>.

<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.08.









NOTE 1—Inside clearance ratio =  $(D_i - D_o)/D_o$

NOTE 2—Dimensional tolerance of  $D_i = \pm 0.003$  in. ( $\pm 0.08$  mm)

FIG. 1 Ring-Lined Barrel Sampling Assembly

inside clearance ratio formula.) The wall thickness of the thin-walled extension shall conform to Table 1.

4.6.1 The thin-walled extension of the shoe shall be perfectly round. Shoes that have become out-of-round for any reason shall not be used. If the thin-walled extension of the shoe deforms during sampling, the sample obtained shall not be used for tests, such as shear strength, where soil disturbance is a factor.

NOTE 2—The thin-walled extension of the shoe is not suitable for stiff or gravelly soils. In cases such as these, a shoe similar to the type specified in Method D 1586 is required for penetration. The use of this type of shoe, however, may result in excessive disturbance of the soil so that it is no longer suitable for shear or consolidation determinations, or both.

4.7 *Sample Extractor*—Specimen-filled rings shall be removed from the sampler by pressing them out or alternatively by the use of a split barrel. The extractor disk shall be at least 0.5 in. (13 mm) thick and shall bear solidly against the sample rings at all points. It shall slide easily inside the sampler barrel without jamming and without free play.

4.8 *Containers for Specimen-Filled Rings*—These shall be snug fitting, tightly sealed (watertight), rigid containers that will not permit movement of the specimen-filled rings inside. They shall be noncorrosive.

4.9 *Miscellaneous Equipment*—This includes a pipe vise, pipe wrenches, spatulas, cleaning brushes, buckets, rags, data sheets, transporting boxes, etc. Water must be available for cleaning the equipment.

## 5. Procedure

5.1 Clean the hole to sampling elevation using whatever method is preferred that will ensure that the material to be sampled is not disturbed. In saturated sands and silts, withdraw the drill bit slowly to prevent loosening of the soil around the hole. When casing is used, it shall not be driven below sampling elevation. Water or drilling liquid within the boring must be maintained at all times at or above the natural ground water level; it is preferable to keep the hole filled.

5.2 Keep a careful record of drill penetration and sampler depth to ensure that the soil being sampled is the original soil at the bottom of the hole and is not contaminated by soil falling down from the sides of the hole. If there is any significant tendency for soil to fall from the sides of the hole to the bottom, use water, drilling mud, or casing, as necessary, in order to prevent this from happening. The process of jetting through an open-tube sampler and then sampling when the desired depth is reached shall not be permitted. The use of bottom-discharge bits shall not be allowed.

5.3 Assemble the sampling assembly and lower it carefully into the hole. With the cutting edge of the shoe resting on the bottom of the hole and the water level in the boring at the ground water level or above, push the sampling assembly into the soil by a continuous and rapid motion without impact or twisting. Push the assembly in far enough so that all cuttings, sludge, and soil disturbed by drilling are in the waste barrel; however, in no case push the assembly farther than the total length of the shoe, sampler, and waste barrel. Take care that none of the sample is lost due to improper operation of the check valve.

5.4 When the soils are so hard that they cannot be penetrated by pushing, using generally acceptable field procedures, and where recovery by pushing in sands is poor, use a driving hammer to drive the sampling assembly. In such a case, record the hammer weight, height of drop, and number of blows.

5.5 Carefully disassemble the sampling assembly in such a manner as to minimize soil disturbance as much as possible. Trim the soil flush with the ends of the sampling barrel, and remove the specimen (consisting of soil plus rings). Slip the container over the specimen-filled rings and cap both ends. Be certain that there is no movement of the specimen-filled rings inside the container and that the specimen was not disturbed while being removed from the barrel and placed in the container. Label the container in a suitable manner. If the soil in the bottom end ring does not protrude from the ring after removing the shoe, do not use the soil in the







bottom ring for tests other than soil classification and moisture content. If the top ring or rings contain voids, depressions, or any material other than the soil which is being sampled, do not use the soil in this ring (or rings) for any purpose whatsoever. The filling of depressions in the end rings with additional soil shall not be permitted. Discard samples that appear to be disturbed or questionable.

5.6 Examine the soil remaining in the shoe for structure, consistency, color, and condition. Record these observations and include them in the report (see 6.1.8).

NOTE 3—The soil remaining in the shoe is relatively undisturbed and therefore may be suitable for a variety of laboratory tests.

## 6. Report

6.1 Data obtained in each boring shall be recorded in the field and shall contain the following:

- 6.1.1 Name and location of job,
- 6.1.2 Date of boring and times of start and finish,
- 6.1.3 Boring number and location,
- 6.1.4 Surface elevation, if available,
- 6.1.5 Sample number and depth,

6.1.6 Method of advancing sampler, penetration, and recovery lengths,

6.1.7 Description and size of sampler,

6.1.8 Description of soil (see Practice D 2488),

6.1.9 Thickness of layer,

6.1.10 Depth to water table or depth of overlying water and time of reading,

6.1.11 Size of casing, depth of cased hole,

6.1.12 Type of drilling equipment—description,

6.1.13 Names of personnel: crewman, field engineer, technician, etc.,

6.1.14 Weather conditions, and

6.1.15 General remarks.

## 7. Precision and Bias

7.1 This practice does not produce numerical or repeatable data and therefore a precision and bias statement is not applicable.

## 8. Keywords

8.1 consolidation; direct shear; identification; liner; representative; ring; sampling

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## Standard Practices for Preserving and Transporting Soil Samples<sup>1</sup>

This standard is issued under the fixed designation D 4220; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 These practices cover procedures for preserving soil samples immediately after they are obtained in the field and accompanying procedures for transporting and handling the samples.

1.2 *Limitations*—These practices are not intended to address requirements applicable to transporting of soil samples known or suspected to contain hazardous materials.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See Section 7.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:

- D 420 Practice for Investigating and Sampling Soil and Rock for Engineering Purposes<sup>2</sup>
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
- D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>
- D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils<sup>2</sup>
- D 1587 Practice for Thin-Walled Tube Sampling of Soils<sup>2</sup>
- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>2</sup>
- D 3550 Practice for Ring-Lined Barrel Sampling of Soils<sup>2</sup>

### 3. Terminology

3.1 Terminology in these practices is in accordance with Terminology D 653.

### 4. Summary of Practices

4.1 The various procedures are given under four groupings as follows:

4.1.1 *Group A*—Samples for which only general visual identification is necessary.

4.1.2 *Group B*—Samples for which only water content and classification tests, proctor and relative density, or profile logging is required, and bulk samples that will be remolded or compacted into specimens for swell pressure,

percent swell, consolidation, permeability, shear testing, CBR, stabilimeter, etc.

4.1.3 *Group C*—Intact, naturally formed or field fabricated, samples for density determinations; or for swell pressure, percent swell, consolidation, permeability testing and shear testing with or without stress-strain and volume change measurements, to include dynamic and cyclic testing

4.1.4 *Group D*—Samples that are fragile or highly sensitive for which tests in Group C are required.

4.2 The procedure(s) to be used should be included in the project specifications or defined by the designated responsible person.

### 5. Significance and Use

5.1 Use of the various procedures recommended in these practices is dependent on the type of samples obtained (Practice D 420), the type of testing and engineering properties required, the fragility and sensitivity of the soil, and the climatic conditions. In all cases, the primary purpose is to preserve the desired inherent conditions.

5.2 The procedures presented in these practices were primarily developed for soil samples that are to be tested for engineering properties, however, they may be applicable for samples of soil and other materials obtained for other purposes.

### 6. Apparatus

6.1 The type of materials and containers needed depend upon the conditions and requirements listed under the four groupings A to D in Section 4, and also on the climate and transporting mode and distance.

6.1.1 *Sealing Wax*, includes microcrystalline wax, paraffin, beeswax, ceresine, carnaubawax, or combination thereof.

6.1.2 *Metal Disks*, about 1/16 in. (about 2 mm) thick and having a diameter slightly less than the inside diameter of the tube, liner, or ring and to be used in union with wax or caulk and tape, or both.

6.1.3 *Wood Disks*, prewaxed, 1 in. (25 mm) thick and having a diameter slightly less than the inside diameter of the liner or tube.

6.1.4 *Tape*, either waterproof plastic, adhesive friction, duct tape.

6.1.5 *Cheesecloth*, to be used in union with wax or alternative layers.

6.1.6 *Caps*, either plastic, rubber or metal, to be placed over the end of thin-walled tubes (Practice D 1587), liners and rings (Practice D 3550), in union with tape or wax.

6.1.7 *O-ring (Sealing End Caps)*, used to seal the ends of samples within thin-walled tubes, by mechanically expanding an O-ring against the tube wall.

<sup>1</sup> These practices are under the jurisdiction of ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 04.08.







NOTE 1—Plastic expandable end caps are preferred. Metal expandable end caps seal equally well; however, long-term storage may cause corrosion problems.

6.1.8 *Jars*, wide mouthed, with rubber-ringed lids or lids lined with a coated paper seal and of a size to comfortably receive the sample, commonly ½ pt (250 mL), 1 pt (500 mL) and quart-sized (1000 mL).

6.1.9 *Bag*, either plastic, burlap with liner, burlap or cloth type (Practice D 1452).

6.1.10 *Packing Material*, to protect against vibration and shock.

6.1.11 *Insulation*, either granule (bead), sheet or foam type, to resist temperature change of soil or to prevent freezing.

6.1.12 *Sample Cube Boxes*, for transporting cube (block) samples. Constructed with ½ to ¾ in. (13 to 19 mm) thick plywood (marine type).

6.1.13 *Cylindrical Sample Containers*, somewhat larger in dimension than the thin-walled tube or liner samples, such as cylindrical frozen food cartons.

6.1.14 *Shipping Containers*, either box or cylindrical type and of proper construction to protect against vibration, shock, and the elements, to the degree required.

NOTE 2—The length, girth and weight restrictions for commercial transportation must be considered.

6.1.15 *Identification Material*—This includes the necessary writing pens, tags, and labels to properly identify the sample(s).

## Precautions

7.1 Special instructions, descriptions, and marking of containers must accompany any sample that may include radioactive, chemical, toxic, or other contaminant material.

7.2 Interstate transportation containment, storage, and disposal of soil samples obtained from certain areas within the United States and the transportation of foreign soils into or through the United States are subject to regulations established by the U.S. Department of Agriculture, Animal, and Plant Health Service, Plant Protection and Quarantine Programs, and possibly to regulations of other federal, state, or local agencies.

7.2.1 Samples shipped by way of common carrier or U.S. Postal Service must comply with the Department of Transportation Hazardous Materials Regulation, 49CFR Part 172.

7.3 Sample traceability records (see Fig. 1) are encouraged and should be required for suspected contaminated samples.

7.3.1 The possession of all samples must be traceable, from collection to shipment to laboratory to disposition, and should be handled by as few persons as possible.

7.3.2 The sample collector(s) should be responsible for initiating the sample traceability record; recording the project, sample identification and location, sample type, date, and the number and types of containers.

7.3.3 A separate traceability record shall accompany each shipment.

7.3.4 When transferring the possession of samples the person(s) relinquishing and receiving the samples shall sign,

date, record the time, and check for completeness of the traceability record.

## 8. Procedure

8.1 *All Samples*—Properly identify samples with tags, labels, and markings prior to transporting them as follows:

8.1.1 Job name or number, or both,

8.1.2 Sampling date,

8.1.3 Sample/boring number and location,

8.1.4 Depth or elevation, or both,

8.1.5 Sample orientation,

8.1.6 Special shipping or laboratory handling instructions, or both, including sampling orientation, and

8.1.7 Penetration test data, if applicable (Test Method D 1586).

8.1.8 Subdivided samples must be identified while maintaining association to the original sample.

8.1.9 If required, sample traceability record.

8.2 *Group A*—Transport samples in any type of container by way of available transportation. If transported commercially, the container need only meet the minimum requirements of the transporting agency and any other requirements necessary to assure against sample loss.

8.3 *Group B*:

8.3.1 Preserve and transport these samples in sealed, moistureproof containers. All containers shall be of sufficient thickness and strength to ensure against breakage and moisture loss. The container types include: plastic bags or pails, glass or plastic (provided they are waterproof) jars, thin walled tubes, liners, and rings. Wrap cylindrical and cube samples in suitable plastic film or aluminum foil, or both, (Note 3) and coat with several layers of wax, or seal in several layers of cheesecloth and wax.

8.3.2 Transport these samples by any available transportation. Ship these samples as prepared or placed in larger shipping containers, including bags, cardboard, or wooden boxes or barrels.

NOTE 3—Some soils may cause holes to develop in aluminum foil, due to corrosion. Avoid direct contact where adverse affects to sample composition are a concern.

8.3.3 *Plastic Bags*—Place the plastic bags as tightly as possible around the sample, squeezing out as much air as possible. They shall be 3 mil or thicker to prevent leakage.

8.3.4 *Glass-Plastic Jars*—If the jar lids are not rubber ringed or lined with new waxed paper seals, seal the lids with wax.

8.3.5 *Plastic Pails*—If the plastic pail lids are not air tight, seal them with wax or tape.

8.3.6 *Thin-Walled Tubes*:

8.3.6.1 *Expandable Packers*—The preferred method of sealing sample ends within tubes is with plastic, expandable packers.

8.3.6.2 *Wax With Disks*—For short-term sealing, paraffin wax is acceptable. For long term sealing (in excess of 3 days) use microcrystalline waxes or combine with up to 15 % beeswax or resin, for better adherence to the wall of the tube and to reduce shrinkage. Several thin layers of wax are preferred over one thick layer. The minimum final thickness shall be 0.4 in. (10 mm).







8.3.6.3 *End Caps*—Seal metal, rubber, or plastic end caps with tape. For long term storage (longer than 3 days), also dip them in wax, applying two or more layers of wax.

8.3.6.4 *Cheesecloth and Wax*—Use alternating layers (a minimum of two each) of cheesecloth and wax to seal each end of the tube and stabilize the sample.

NOTE 4—Where necessary, spacers or appropriate packing materials, or both, must be placed prior to sealing the tube ends to provide proper confinement. Packing material must be nonabsorbent and must maintain its properties to provide the same degree of continued sample support.

8.3.7 *Liners and Rings*—Refer to 8.3.6.3 or 8.3.6.4.

8.3.8 *Exposed Samples*:

8.3.8.1 *Cylindrical, Cubical or Other Samples Wrapped in Plastic*, such as polyethylene and polypropylene, or foil should be further protected with a minimum of three coats of wax.

8.3.8.2 *Cylindrical and Cube Samples Wrapped in Cheesecloth and Wax*, shall be sealed with a minimum of three layers of each, placed alternatively.

8.3.8.3 *Carton Samples (Frozen Food Cartons)*—Samples placed in these containers must be situated so that wax can be poured completely around the sample. The wax should fill the void between the sample and container wall. The wax should be sufficiently warm to flow, but not so hot that it penetrates the pores of the soil. Generally, the samples should be wrapped in plastic or foil before being surrounded with wax.

8.4 *Group C*:

8.4.1 Preserve and seal these samples in containers as covered in 8.3. In addition, they must be protected against vibration and shock, and protected from extreme heat or cold.

8.4.2 Samples transported by the sampling or testing agency personnel on seats of automobiles and trucks need only be placed in cardboard boxes, or similar containers into which the sealed samples fit snugly, preventing bumping, rolling, dropping, etc.

8.4.3 For all other methods of transporting samples, including automobile trunk, bus, parcel services, truck, boat, air, etc., place the sealed samples in wood, metal, or other type of suitable shipping containers that provide cushioning or insulation, or both, for each sample and container. Avoid transporting by any agency whose handling of containers is suspect.

8.4.4 The cushioning material (sawdust, rubber, polystyrene, urethane foam, or material with similar resiliency) should completely encase each sample. The cushioning between the samples and walls of the shipping containers should have a minimum thickness of 1 in. (25 mm). A minimum thickness of 2 in. (50 mm) shall be provided on the container floor.

8.4.5 When required, the samples should be shipped in the same orientation in which they were sampled. Otherwise, special conditions shall be provided such as freezing, controlled drainage, or sufficient confinement, or a combination thereof, to maintain sample integrity.

8.5 *Group D*:

8.5.1 The requirements of 8.4 must be met, in addition to the following:

8.5.1.1 Samples should be handled in the same orientation in which they were sampled, including during transportation or shipping, with appropriate markings on the shipping container.

8.5.1.2 For all modes of private or commercial transportation, the loading, transporting and unloading of the shipment containers should be supervised as much as possible by a qualified person.

NOTE 5—A qualified person may be an engineer, geologist, soil scientist, soils technician or responsible person designated by the project manager.

8.6 *Shipping Containers* (see Figs. 2 to 7 for typical containers):

8.6.1 The following features should be included in the design of the shipping container for Groups C and D.

8.6.1.1 It should be reuseable,

8.6.1.2 It should be constructed so that the samples can be maintained, at all times, in the same position as when sampled or packed, or both,

8.6.1.3 It should include sufficient packing material to cushion or isolate, or both, the tubes from the adverse effect of vibration and shock, and

8.6.1.4 It should include sufficient insulating material to prevent freezing, sublimation and thawing, or undesirable temperature changes.

8.6.2 *Wood Shipping Containers*:

8.6.2.1 Wood is preferred over metal. Outdoor (marine) plywood having a thickness of  $\frac{1}{2}$  and  $\frac{3}{4}$  in. (13 to 19 mm) may be used. The top (cover) should be hinged and latched, or fastened with screws.

8.6.2.2 The cushioning requirements are given in 8.4.4.

8.6.2.3 For protection against freezing or extreme temperature variation, the entire shipping container should be lined with a minimum insulation thickness of 2 in. (50 mm).

8.6.3 *Metal Shipping Containers*—The metal shipping containers must incorporate cushioning and insulation material to minimum thicknesses in accordance with 8.6.2, although slightly greater thicknesses would be appropriate. Alternatively, the cushion effect could be achieved with a spring suspension system, or any other means that would provide similar protection.

8.6.4 *Styrene Shipping Containers*—Bulk styrene with slots cut to the dimensions of the sample tube or liner. A protective outer box of plywood or reinforced cardboard is recommended.

8.6.5 *Other Containers*—Containers constructed with laminated fiberboard, plastic or reinforced cardboard outer walls, and properly lined, may also be used.

## 9. Reporting

9.1 The data obtained in the field shall be recorded and should include the following:

9.1.1 Job name or number, or both,

9.1.2 Sampling date(s),

9.1.3 Sample/boring number(s) and location(s),

9.1.4 Depth(s) or elevation(s), or both,

9.1.5 Sample orientation,







### Sample Identification/Traceability Record (Controlled Document)

Project: \_\_\_\_\_  
Shipped by: \_\_\_\_\_  
Shipped to: \_\_\_\_\_  
Comments: \_\_\_\_\_

W.O. \_\_\_\_\_

Attention of:  
Hazardous materials suspected?  
(yes/no)

[illegible]

Sampler(s) (signature) \_\_\_\_\_

[illegible]

Shipment prepared by: (signature) \_\_\_\_\_ Date/Time \_\_\_\_\_ Shipment method: \_\_\_\_\_

Received for Lab by: (signature) \_\_\_\_\_ Date/Time \_\_\_\_\_ Comments \_\_\_\_\_

Receiving Laboratory: Please return original form after signing for receipt of samples.

**FIG. 1 Example Layout of Record Form**

- 9.1.6 Groundwater observation, if any,  
9.1.7 Method of sampling, and penetration test data, if applicable,  
9.1.8 Sample dimensions,  
9.1.9 Soil description (Practice D 2488),  
9.1.10 Names of technician/crewman, engineer, project chief, etc.,  
9.1.11 Comments regarding contaminated or possible contaminated samples.

- 9.1.12 If used, a copy of traceability records,  
9.1.13 Weather conditions, and  
9.1.14 General remarks.

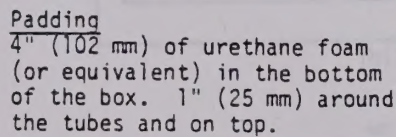
## 10. Precision and Bias

10.1 This practice provides qualitative and general information only. Therefore, a precision and bias statement is not applicable.







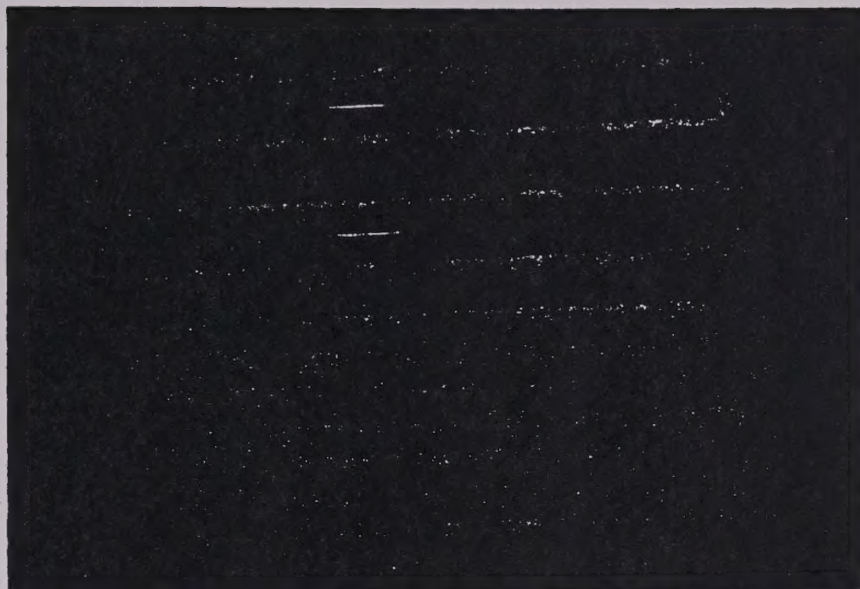


3/4" (19 mm) thick plywood  
(exterior grade)

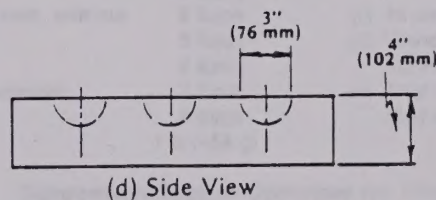
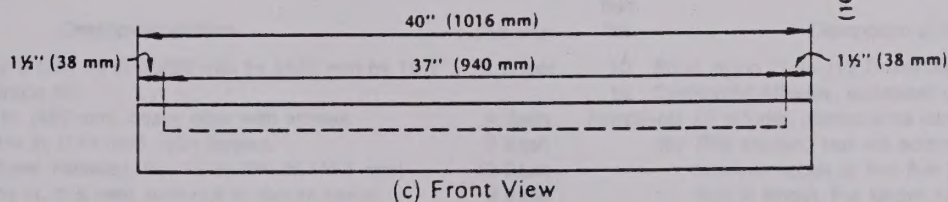
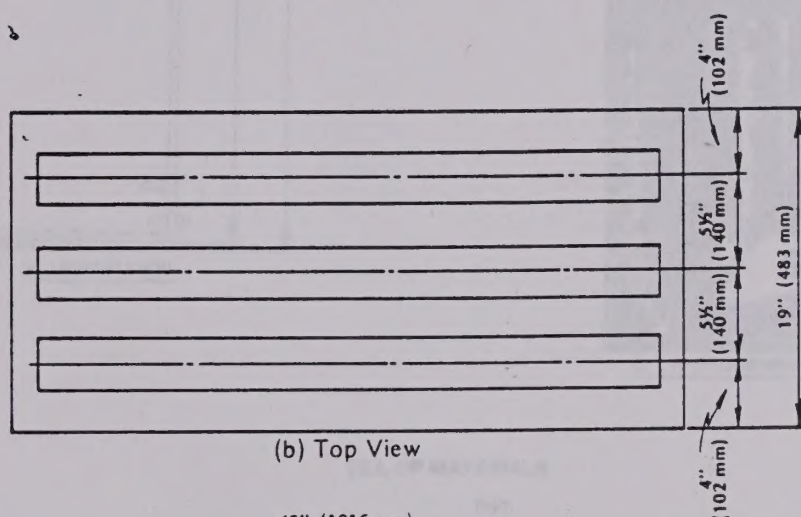








(a) Photo of Open Box For 5" (127 mm) Tubes



NOTE—Top and bottom halves are identical.

FIG. 3 Styrene Shipping Container for 3-in. (76-mm) Thin-Walled Tubes





Fig. 1. Schematic diagram of the experimental setup.

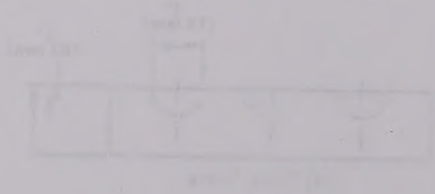
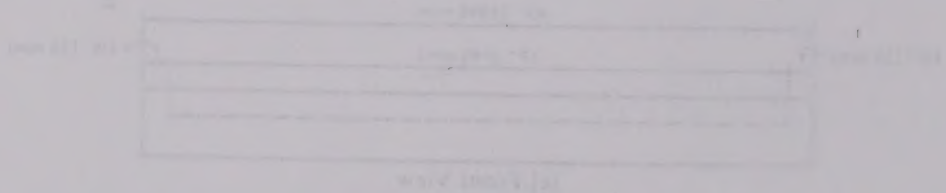
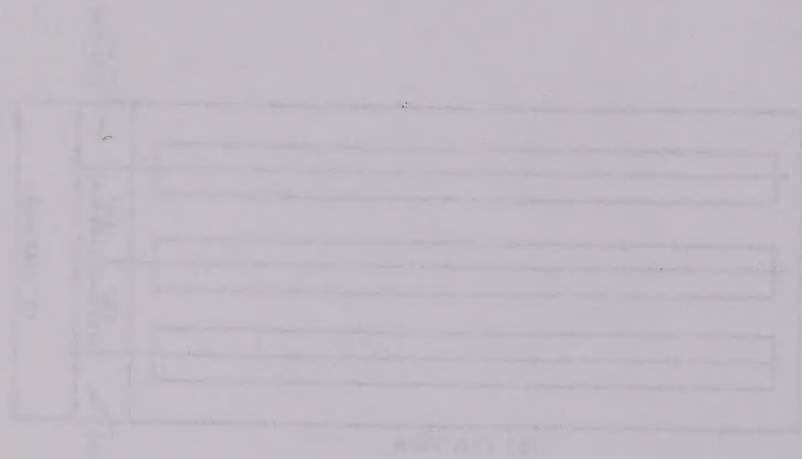
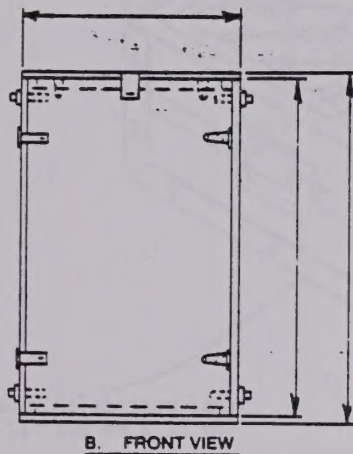
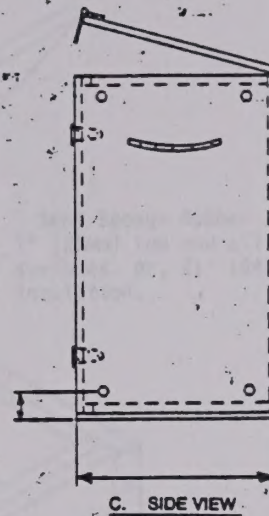
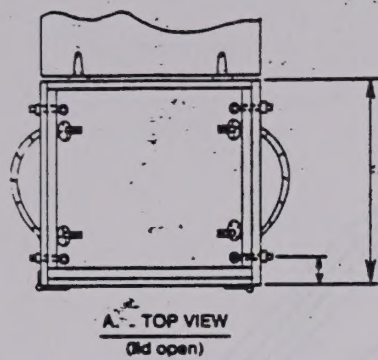


Fig. 2. Schematic diagram of the experimental setup.





D. PHOTOGRAPH OF OPEN BOX

# BILL OF MATERIALS

Item No.	Description of Item	Quantity	Item No.	Description of Item	Quantity
1	Plywood, 4 ft by 8 ft by 3/4 in. (1220 mm by 2440 mm by 19.1 mm) exterior, Grade AC	1 Sheet	13	Rope, nylon, 1/2-in. (12.7-mm) diameter, solid braided	5 ft (1524 mm)
2	Hinge, strap, 4 in. (102 mm), heavy duty with screws	4 Each	14	Cushioning Material, expanded polystyrene foam	10 ft <sup>3</sup> (0.28 m <sup>3</sup> )
3	Hasp, hinged, 4 1/2 in. (114 mm), with screws	3 Each	NOTES—(a) All wooden components can be sawed from one sheet of plywood.		
4	Screw, Wood, Steel, Flathead, No. 10 by 1 3/4 in. (44.5 mm)	72 Each			
5	Bolt, Machine, 3/8 in. (9.5 mm), with nut to secure hasps	3 Each	(b) This shipping box will accommodate approximately three 3-in. (76-mm) diameter tubes or two 5-in (127-mm) diameter tubes up to 30 in. (762 mm) in length. For longer tubes the inside height of the box must be a minimum of 6-in. (152 mm) greater than the length of the tube.		
6	Washer, flat, 3/8 in. (9.5 mm)	3 Each			
7	Eye Bolt, 1/2 by 2 in. (6.4 mm by 51 mm), zinc-plated, with nut	8 Each	(c) All joints to be glued and fastened with screws.		
8	Washer, flat, 1/4 in. (6.4 mm), for hasp bolt	8 Each			
9	S Hooks, 2 in. (51 mm), open, zinc-plated	8 Each	(d) Stencil all sides as follows (See Views B and C). TO PROTECT FROM FREEZING		
10	Clamp, adjustable, hose, steel, worm screw adjustment	2 Each			
11	Spring, expansion	8 Each	(e) After suspending samples as indicated above, all void space must be filled with a suitable resilient packing material.		
12	Adhesive, woodworking	1 lb (454 g)			

FIG. 4 Suspension System Container for Thin-Walled Tubes





FIG. 1

FIG. 2	FIG. 3	FIG. 4	FIG. 5
<p>FIG. 2 is a perspective view of the device showing the housing 10 and the lid 12. The housing 10 is formed by a front wall 14, a rear wall 16, and side walls 18. The lid 12 is formed by a top wall 20 and side walls 22. The housing 10 and lid 12 are joined together by a hinge 24. The device is shown in an open position.</p>	<p>FIG. 3 is a perspective view of the device showing the housing 10 and the lid 12. The housing 10 is formed by a front wall 14, a rear wall 16, and side walls 18. The lid 12 is formed by a top wall 20 and side walls 22. The housing 10 and lid 12 are joined together by a hinge 24. The device is shown in a closed position.</p>	<p>FIG. 4 is a perspective view of the device showing the housing 10 and the lid 12. The housing 10 is formed by a front wall 14, a rear wall 16, and side walls 18. The lid 12 is formed by a top wall 20 and side walls 22. The housing 10 and lid 12 are joined together by a hinge 24. The device is shown in an open position.</p>	<p>FIG. 5 is a perspective view of the device showing the housing 10 and the lid 12. The housing 10 is formed by a front wall 14, a rear wall 16, and side walls 18. The lid 12 is formed by a top wall 20 and side walls 22. The housing 10 and lid 12 are joined together by a hinge 24. The device is shown in a closed position.</p>

FIG. 2



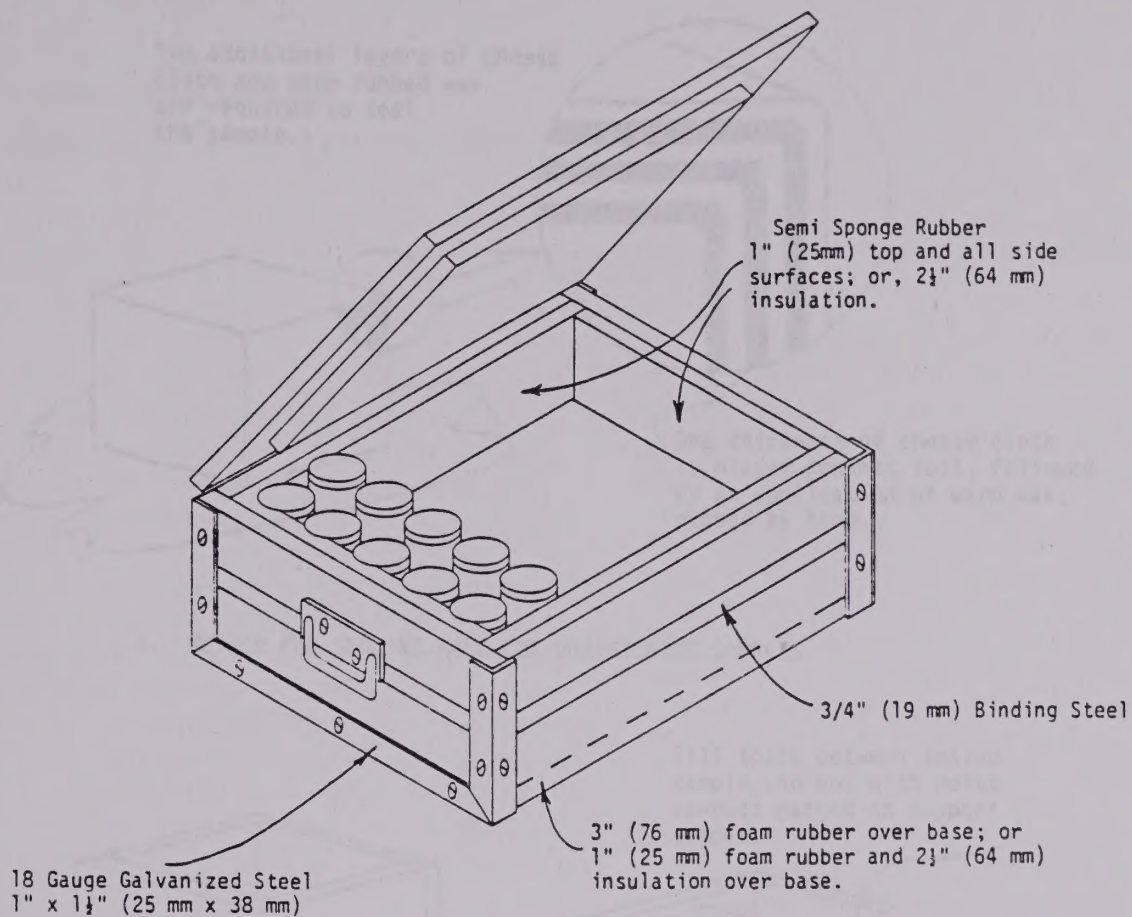


FIG. 6 Shipping Box for Liner (Short Tube) or Ring Samples



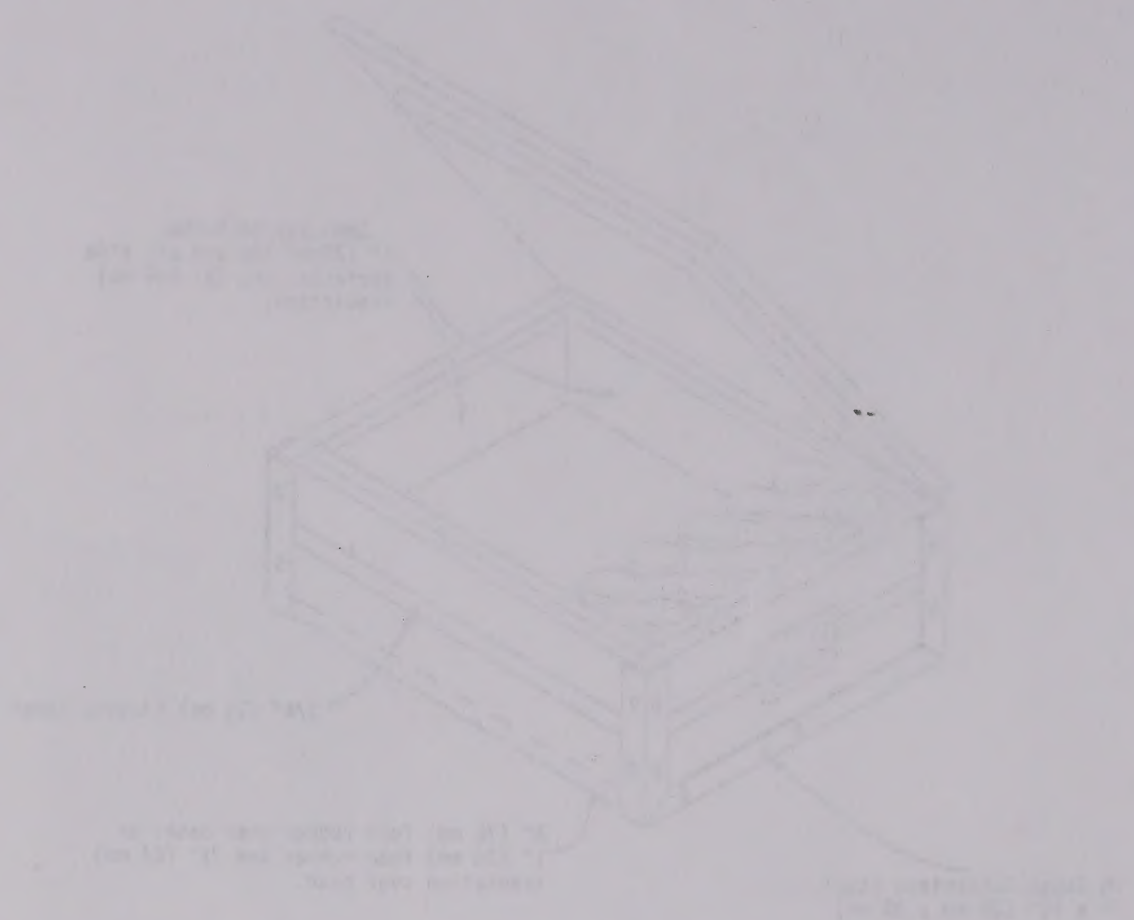
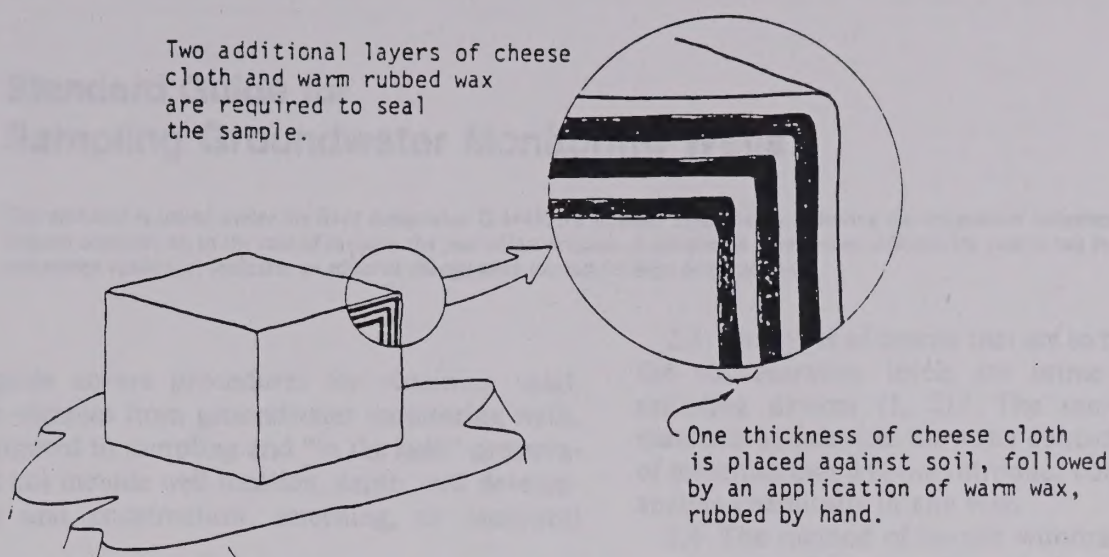
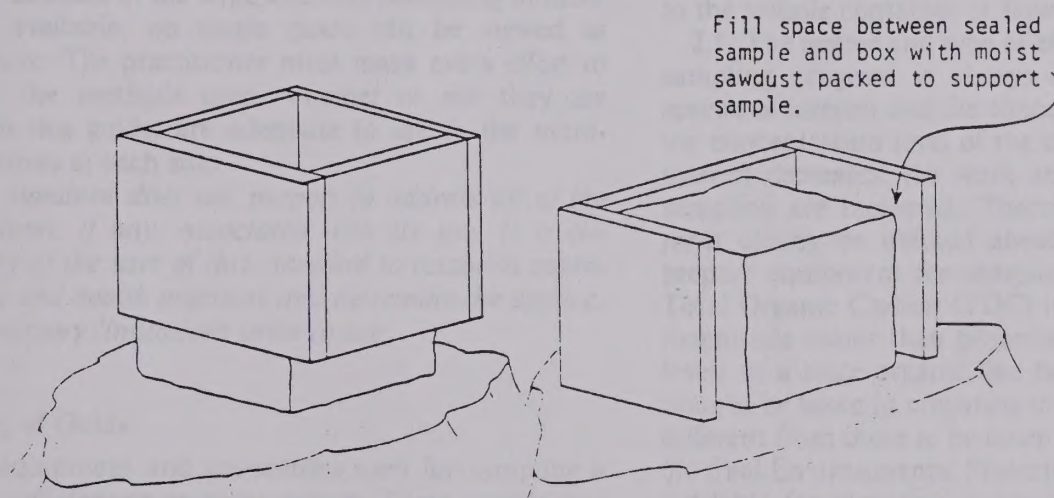


FIG. 1. Perspective view of the box (open lid) in the exploded view.





A. METHOD FOR SEALING HAND-CUT UNDISTURBED SAMPLES



B. ENCASE EASILY DISTURBED SAMPLES IN BOX PRIOR TO CUTTING

Box constructed with 1/2"-3/4" ( 13 - 19 mm) exterior plywood.

FIG. 7 Preparing and Packaging a Block Sample

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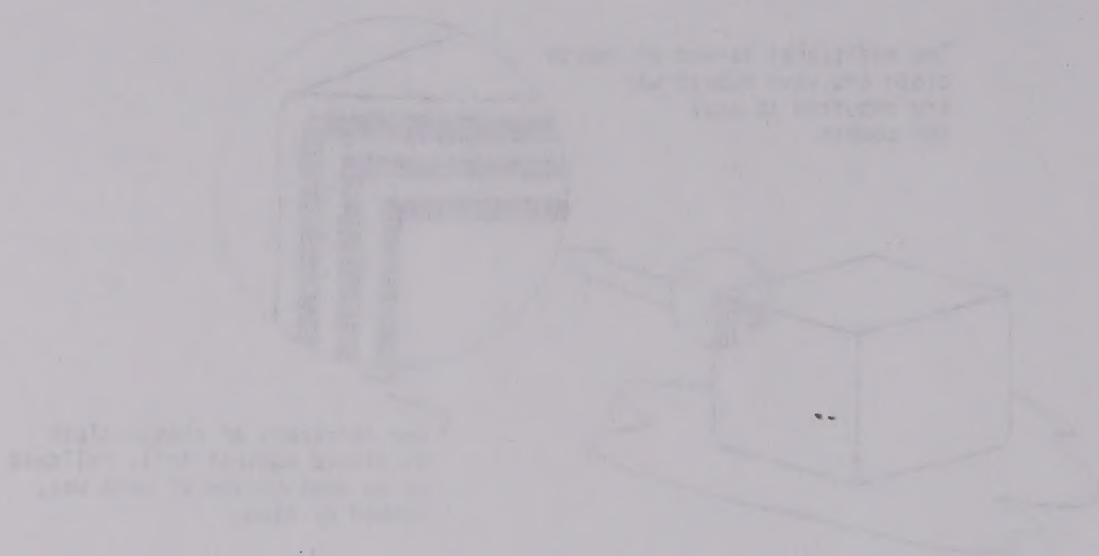


Fig. 1. Schematic diagram of the device.



Fig. 2. Schematic diagram of the device with a small protrusion.

Fig. 3. Schematic diagram of the device with a small protrusion.

Fig. 4. Schematic diagram of the device with a small protrusion.

The diagram shows the device with a small protrusion on its top surface. The device is a cube with a small, rounded protrusion on its top surface. The diagram is a schematic representation of the device.

The diagram shows the device with a small protrusion on its top surface. The device is a cube with a small, rounded protrusion on its top surface. The diagram is a schematic representation of the device.





## Standard Guide for Sampling Groundwater Monitoring Wells<sup>1</sup>

This standard is issued under the fixed designation D 4448; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This guide covers procedures for obtaining valid, representative samples from groundwater monitoring wells. The scope is limited to sampling and “in the field” preservation and does not include well location, depth, well development, design and construction, screening, or analytical procedures.

1.2 This guide is only intended to provide a review of many of the most commonly used methods for sampling groundwater quality monitoring wells and is not intended to serve as a groundwater monitoring plan for any specific application. Because of the large and ever increasing number of options available, no single guide can be viewed as comprehensive. The practitioner must make every effort to ensure that the methods used, whether or not they are addressed in this guide, are adequate to satisfy the monitoring objectives at each site.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Summary of Guide

2.1 The equipment and procedures used for sampling a monitoring well depend on many factors. These include, but are not limited to, the design and construction of the well, rate of groundwater flow, and the chemical species of interest. Sampling procedures will be different if analyzing for trace organics, volatiles, oxidizable species, or trace metals is needed. This guide considers all of these factors by discussing equipment and procedure options at each stage of the sampling sequence. For ease of organization, the sampling process can be divided into three steps: well flushing, sample withdrawal, and field preparation of samples.

2.2 Monitoring wells must be flushed prior to sampling so that the groundwater is sampled, not the stagnant water in the well casing. If the well casing can be emptied, this may be done although it may be necessary to avoid oxygen contact with the groundwater. If the well cannot be emptied, procedures must be established to demonstrate that the sample represents groundwater. Monitoring an indicative parameter such as pH during flushing is desirable if such a parameter can be identified.

2.3 The types of species that are to be monitored as well as the concentration levels are prime factors for selecting sampling devices (1, 2).<sup>2</sup> The sampling device and all materials and devices the water contacts must be constructed of materials that will not introduce contaminants or alter the analyte chemically in any way.

2.4 The method of sample withdrawal can vary with the parameters of interest. The ideal sampling scheme would employ a completely inert material, would not subject the sample to negative pressure and only moderate positive pressure, would not expose the sample to the atmosphere, or preferably, any other gaseous atmosphere before conveying it to the sample container or flow cell for on-site analysis.

2.5 The degree and type of effort and care that goes into a sampling program is always dependent on the chemical species of interest and the concentration levels of interest. As the concentration level of the chemical species of analytical interest decreases, the work and precautions necessary for sampling are increased. Therefore, the sampling objective must clearly be defined ahead of time. For example, to prepare equipment for sampling for mg/L (ppm) levels of Total Organic Carbon (TOC) in water is about an order of magnitude easier than preparing to sample for  $\mu\text{g/L}$  (ppb) levels of a trace organic like benzene. The specific precautions to be taken in preparing to sample for trace organics are different from those to be taken in sampling for trace metals. No final Environmental Protection Agency (EPA) protocol is available for sampling of trace organics. A short guidance manual, (3) and an EPA document (4) concerning monitoring well sampling, including considerations for trace organics are available.

2.6 Care must be taken not to cross contaminate samples or monitoring wells with sampling or pumping devices or materials. All samples, sampling devices, and containers must be protected from the environment when not in use. Water level measurements should be made before the well is flushed. Oxidation-reduction potential, pH, dissolved oxygen, and temperature measurements and filtration should all be performed on the sample in the field, if possible. All but temperature measurement must be done prior to any significant atmospheric exposure, if possible.

2.7 The sampling procedures must be well planned and all sample containers must be prepared and labeled prior to going to the field.

### 3. Significance and Use

3.1 The quality of groundwater has become an issue of national concern. Groundwater monitoring wells are one of

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee D-34 on Waste Management and is the direct responsibility of Subcommittee D34.01 on Sampling and Monitoring.

Current edition approved Aug. 23 and Oct. 25, 1985. Published May 1986.

<sup>2</sup> The boldface numbers in parentheses refer to a list of references at the end of this guide.







**TABLE 1 Typical Container and Preservation Requirements for a Ground-Water Monitoring Program**

Sample and Measurement	Volume Required (mL)	Container P—Polyethylene G—Glass	Preservative	Maximum Holding Time
Metals As/Ba/Cd/Cr/Fe Pb/Se/ Ag/Mn/Na	1000–2000	P/G (special acid cleaning)	high purity nitric acid to pH <2	6 months
Mercury	200–300	P/G (special acid cleaning)	high purity nitric acid to pH <2 +0.05 % K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	28 days
Radioactivity alpha/beta/radium	4000	P/G (special acid cleaning)	high purity nitric acid to pH <2	6 months
Phenolics	500–1000	G	cool, 4°C H <sub>2</sub> SO <sub>4</sub> to pH <2	28 days
Miscellaneous	1000–2000	P	cool, 4°C	28 days
Fluoride	300–500	P		28 days
Chloride	50–200	P/G		28 days
Sulfate	100–500	P/G		48 hours
Nitrate	100–250	P/G		6 h
Coliform	100	P/G		on site/24 h
Conductivity	100	P/G		on site/6 h
pH	100	P/G		48 h
Turbidity	100	P/G		
Total organic carbon (TOC)	25–100	P/G	cool, 4°C or cool, 4°C HCl or H <sub>2</sub> SO <sub>4</sub> to pH <2	24 h 28 days
Pesticides, herbicides and total organic halogen (TOX)	1000–4000	G/TFE-fluoro- carbon lined cap solvent rinsed	cool, 4°C	7 days/extraction +30 days/analysis
Extractable organics	1000–2000	G/TFE-fluoro- carbon-lined cap solvent rinsed	cool, 4°C	7 days/extraction +30 days/analysis
Organic purgeables acrolein/acrylonitrile	25–120	G/vial TFE-fluorocar- bon-lined sep- tum	cool, 4°C	14 days 3 days

the more important tools for evaluating the quality of groundwater, delineating contamination plumes, and establishing the integrity of hazardous material management facilities.

3.2 The goal in sampling groundwater monitoring wells is to obtain samples that are truly representative of the aquifer or groundwater in question. This guide discusses the advantages and disadvantages of various well flushing, sample withdrawal, and sample preservation techniques. It reviews the parameters that need to be considered in developing a valid sampling plan.

#### 4. Well Flushing (Purging)

4.1 Water that stands within a monitoring well for a long period of time may become unrepresentative of formation water because chemical or biochemical change may cause water quality alterations and even if it is unchanged from the time it entered the well, the stored water may not be representative of formation water at the time of sampling, or both. Because the representativeness of stored water is questionable, it should be excluded from samples collected from a monitoring well.

4.2 The surest way of accomplishing this objective is to remove all stored water from the casing prior to sampling. Research with a tracer in a full scale model 2 in. PVC well (5) indicates that pumping 5 to 10 times the volume of the well via an inlet near the free water surface is sufficient to remove all the stored water in the casing. The volume of the well may

be calculated to include the well screen and any gravel pack if natural flow through these is deemed insufficient to keep them flushed out.

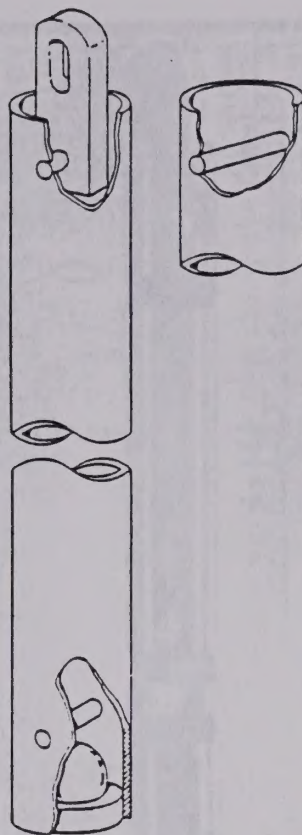
4.3 In deep or large diameter wells having a volume of water so large as to make removal of all the water impractical, it may be feasible to lower a pump or pump inlet to some point well below the water surface, purge only the volume below that point then withdraw the sample from a deeper level. Research indicates this approach should avoid most contamination associated with stored water (5, 6, 7). Sealing the casing above the purge point with a packer may make this approach more dependable by preventing migration of stored water from above. But the packer must be above the top of the screened zone, or stagnant water from above the packer will flow into the purged zone through the well's gravel/sand pack.

4.4 In low yielding wells, the only practical way to remove all standing water may be to empty the casing. Since it is not always possible to remove all water, it may be advisable to let the well recover (refill) and empty it again at least once. If introduction of oxygen into the aquifer may be of concern, it would be best not to uncover the screen when performing the above procedures. The main disadvantage of methods designed to remove all the stored water is that large volumes may need to be pumped in certain instances. The main advantage is that the potential for contamination of samples with stored water is minimized.









NOTE—Taken from Ref (15).

FIG. 1 Single Check Valve Bailer

4.5 Another approach to well flushing is to monitor one or more indicator parameters such as pH, temperature, or conductivity and consider the well to be flushed when the indicator(s) no longer change. The advantage of this method is that pumping can be done from any location within the casing and the volume of stored water present has no direct bearing on the volume of water that must be pumped. Obviously, in a low yielding well, the well may be emptied before the parameters stabilize. A disadvantage of this approach is that there is no assurance in all situations that the stabilized parameters represent formation water. If significant drawdown has occurred, water from some distance away may be pulled into the screen causing a steady parameter reading but not a representative reading. Also, a suitable indicator parameter and means of continuously measuring it in the field must be available.

4.6 Gibb (4, 8) has described a time-drawdown approach using a knowledge of the well hydraulics to predict the percentage of stored water entering a pump inlet near the top of the screen at any time after flushing begins. Samples are taken when the percentage is acceptably low. As before, the advantage is that well volume has no direct effect in the duration of pumping. A current knowledge of the well's hydraulic characteristics is necessary to employ this approach. Downward migration of stored water due to effects other than drawdown (for example density differences) is not accounted for in this approach.

4.7 In any flushing approach, a withdrawal rate that minimizes drawdown while satisfying time constraints should be used. Excessive drawdown distorts the natural flow patterns around a well and can cause contaminants that were not present originally to be drawn into the well.

## 5. Materials and Manufacture

5.1 The choice of materials used in the construction of sampling devices should be based upon a knowledge of what compounds may be present in the sampling environment and how the sample materials may interact via leaching, adsorption, or catalysis. In some situations, PVC or some other plastic may be sufficient. In others, an all glass apparatus may be necessary.

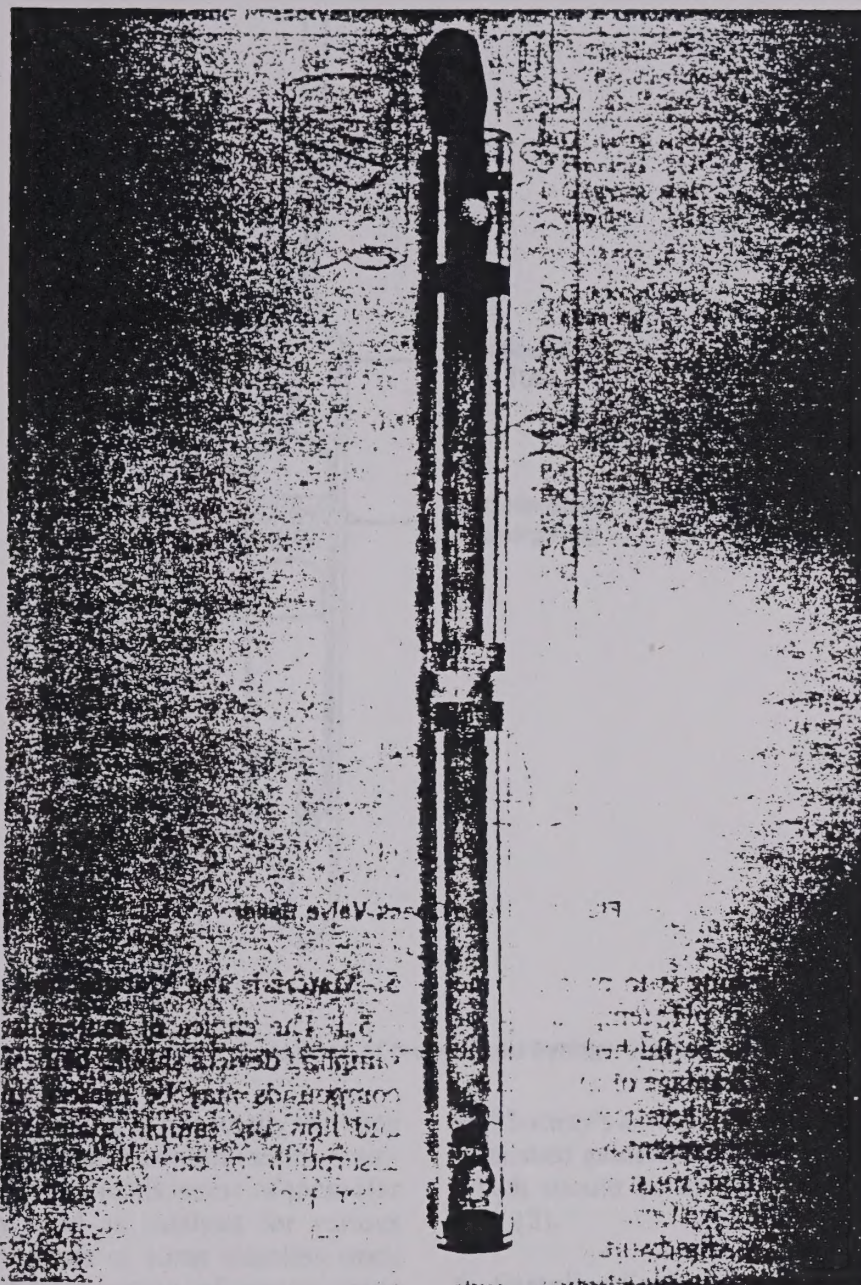
5.2 Most analytical protocols suggest that the devices used in sampling and storing samples for trace organics analysis ( $\mu\text{g/L}$  levels) must be constructed of glass or TFE-fluorocarbon resin, or both. One suggestion advanced by the EPA is that the monitoring well be constructed so that only TFE-fluorocarbon tubing be used in that portion of the sampling well that extends from a few feet above the water table to the bottom of the borehole. (3, 5) Although this type of well casing is now commercially available, PVC well casings are currently the most popular. If adhesives are avoided, PVC well casings are acceptable in many cases although their use may still lead to some problems if trace organics are of concern. At present, the type of background presented by PVC and interactions occurring between PVC and groundwater are not well understood. Tin, in the form of an organotin stabilizer added to PVC, may enter samples taken from PVC casing. (9)

5.3 Since the most significant problem encountered in trace organics sampling, results from the use of PVC adhesives in monitoring well construction, threaded joints might avoid the problem (3, 5). Milligram per litre (parts per million) levels of compounds such as tetrahydrofuran, methyl-ethyl-ketone, and toluene are found to leach into









NOTE—Taken from Ref (17).

FIG. 2 Acrylic Point Source Bailer

groundwater samples from monitoring well casings sealed with PVC solvent cement. Pollutant phthalate esters (8, 10) are often found in water samples at ppb levels; the EPA has found them on occasion at ppm levels in their samples. The ubiquitous presence of these phthalate esters is unexplained, except to say that they may be leached from plastic pipes, sampling devices, and containers.

5.4 TFE-fluorocarbon resins are highly inert and have sufficient mechanical strength to permit fabrication of sampling devices and well casings. Molded parts are exposed to high temperature during fabrication which destroys any organic contaminants. The evolution of fluorinated compounds can occur during fabrication, will cease rapidly, and does not occur afterwards unless the resin is heated to its melting point.

5.5 Extruded tubing of TFE-fluorocarbon for sampling may contain surface traces of an organic solvent extrusion aid. This can be removed easily by the fabricator and, once

removed by flushing, should not affect the sample. TFE-fluorocarbon FEP and TFE-fluorocarbon PFA resins do not require this extrusion aid and may be suitable for sample tubing as well. Unsintered thread-sealant tape of TFE-fluorocarbon is available in an "oxygen service" grade and contains no extrusion aid and lubricant.

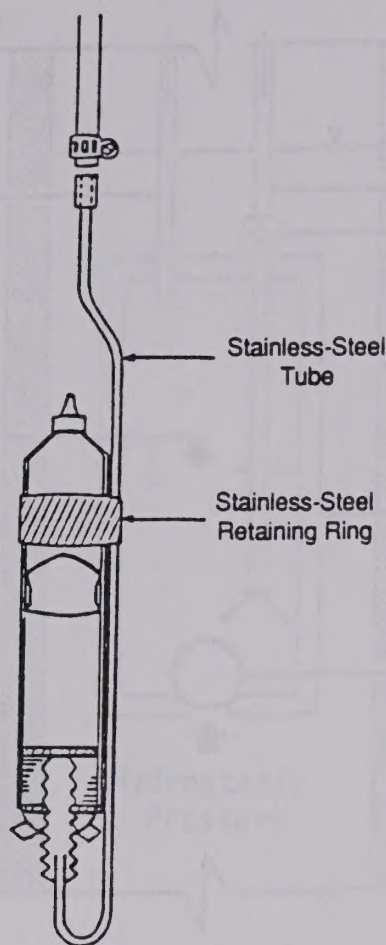
5.6 Louneman, et al. (11) alludes to problems caused by a lubricating oil used during TFE-fluorocarbon tubing extrusion. This reference also presents evidence that a fluorinated ethylene-propylene copolymer adsorbed acetone to a degree that later caused contamination of a gas sample.

5.7 Glass and stainless steel are two other materials generally considered inert in aqueous environments. Glass is probably among the best choices though it is not inconceivable it could adsorb some constituents as well as release other contaminants (for example, Na, silicate, and Fe). Of course, glass sampling equipment must be handled carefully in the field. Stainless steel is strongly and easily machined to









NOTE—Taken from Ref (21).

FIG. 3 Schematic of the Inverted Syringe Sampler

fabricate equipment. Unfortunately, it is not totally immune to corrosion that could release metallic contaminants. Stainless steel contains various alloying metals, some of these (for example Ni) are commonly used as catalysts for various reactions. The alloyed constituents of some stainless steels can be solubilized by the pitting action of nonoxidizing anions such as chloride, fluoride, and in some instances sulfate, over a range of pH conditions. Aluminum, titanium, polyethylene, and other corrosion resistant materials have been proposed by some as acceptable materials, depending on groundwater quality and the constituents of interest.

5.8 Where temporarily installed sampling equipment is used, the sampling device that is chosen should be non-plastic (unless TFE-fluorocarbon), cleanable of trace organics, and must be cleaned between each monitoring well use in order to avoid cross-contamination of wells and samples. The only way to ensure that the device is indeed "clean" and acceptable is to analyze laboratory water blanks and field water blanks that have been soaked in and passed through the sampling device to check for the background levels that may result from the sampling materials or from field conditions. Thus, all samplings for trace materials should be accompanied by samples which represent the field background (if possible), the sampling equipment background, and the laboratory background.

5.9 Additional samples are often taken in the field and spiked (spiked-field samples) in order to verify that the sample handling procedures are valid. The American Chem-

ical Society's committee on environmental improvement has published guidelines for data acquisition and data evaluation which should be useful in such environmental evaluations (10, 12).

## 6. Sampling Equipment

6.1 There is a fairly large choice of equipment presently available for groundwater sampling from single screened wells and well clusters. The sampling devices can be categorized into the following eight basic types.

### 6.1.1 Down-Hole Collection Devices:

6.1.1.1 Bailers, messenger bailers, or thief samplers (13, 14) are examples of down-hole devices that probably provide valid samples once the well has been flushed. They are not practical for removal of large volumes of water. These devices can be constructed in various shapes and sizes from a variety of materials. They do not subject the sample to pressure extremes.

6.1.1.2 Bailers do expose part of the sample to the atmosphere during withdrawal. Bailers used for sampling of volatile organic compounds should have a sample cock or draft valve in or near the bottom of the sampler allowing withdrawal of a sample from the well below the exposed surface of the water or the first few inches of the sample should be discarded. Suspension lines for bailers and other samplers should be kept off the ground and free of other contaminating materials that could be carried into the well. Down-hole devices are not very practical for use in deep





Fig. 1. Schematic diagram of the storage tank.

The design of the storage tank is based on the following requirements: 1) The tank must be able to store a large volume of liquid. 2) The tank must be able to withstand high internal pressures. 3) The tank must be able to withstand high temperatures. 4) The tank must be able to withstand high mechanical stresses. 5) The tank must be able to withstand high corrosion rates.

### 3.1. Design of the storage tank

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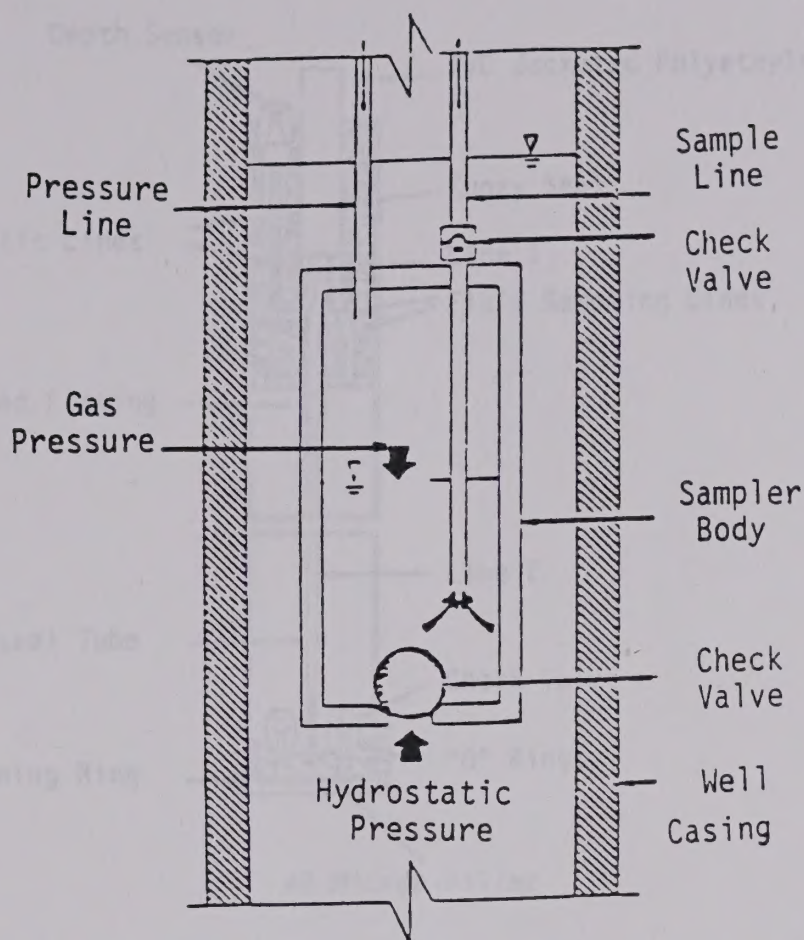
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NOTE—Taken from Ref (5).

FIG. 4 The Principal of Gas Displacement Pumping

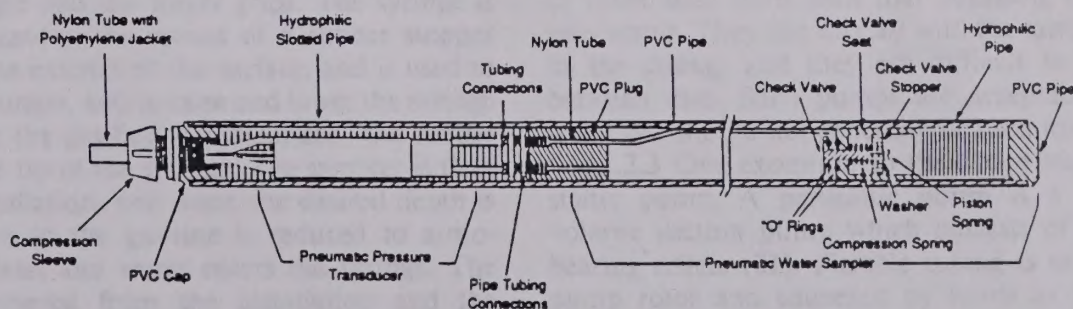
wells. However, potential sample oxidation during transfer of the sample into a collection vessel and time constraints for lowering and retrieval for deep sampling are the primary disadvantages.

6.1.1.3 Three down-hole devices are the single and double check valve bailers and thief samplers. A schematic of a single check valve unit is illustrated in Fig. 1. The bailer may be threaded in the middle so that additional lengths of blank casing may be added to increase the sampling volume. TFE-fluorocarbon or PVC are the most common materials used for construction (15).

6.1.1.4 In operation, the single check valve bailer is lowered into the well, water enters the chamber through the bottom, and the weight of the water column closes the check

valve upon bailer retrieval. The specific gravity of the ball should be about 1.4 to 2.0 so that the ball almost sits on the check valve seat during chamber filling. Upon bailer withdrawal, the ball will immediately seat without any samples loss through the check valve. A similar technique involves lowering a sealed sample container within a weighted bottle into the well. The stopper is then pulled from the bottle via a line and the entire assembly is retrieved upon filling of the container (14, 16).

6.1.1.5 A double check valve bailer allows point source sampling at a specific depth (15, 17). An example is shown in Fig. 2. In this double check valve design, water flows through the sample chamber as the unit is lowered. A venturi tapered inlet and outlet ensures that water passes freely through the



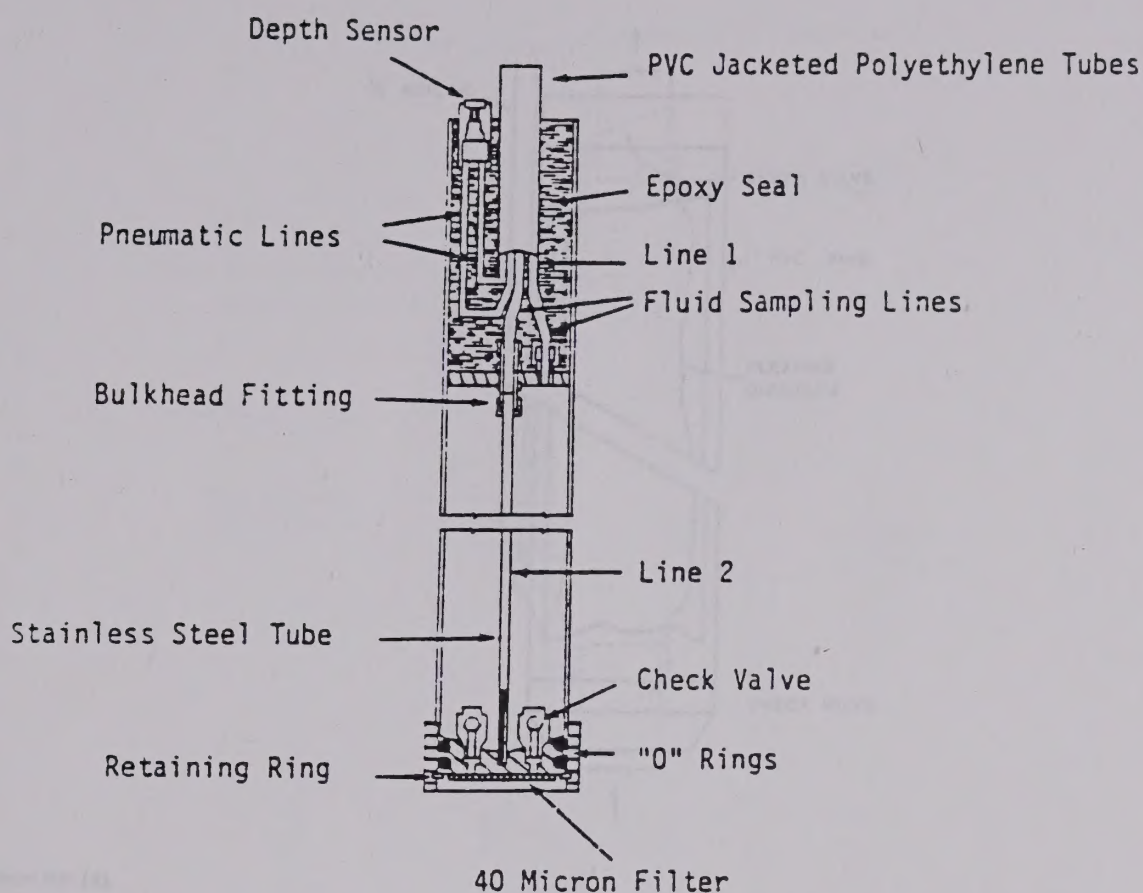
NOTE—Taken from Ref (41).

FIG. 5 Pneumatic Water Sampler With Internal Transducer









NOTE—Taken from Ref (42).

FIG. 6 Pneumatic Sampler With Externally Mounted Transducer

unit. When a depth where the sample is to be collected is reached, the unit is retrieved. Because the difference between each ball and check valve seat is maintained by a pin that blocks vertical movement of the check ball, both check valves close simultaneously upon retrieval. A drainage pin is placed into the bottom of the bailer to drain the sample directly into a collection vessel to reduce the possibility of air oxidation. The acrylic model in Fig. 2 is threaded at the midsection allowing the addition of threaded casing to increase the sampling volume.

6.1.1.6 Another approach for obtaining point source samples employs a weighted messenger or pneumatic change to "trip" plugs at either end of an open tube (for example, tube water sampler or thief sampler) to close the chamber (18). Foerst, Kemmerer, and Bacon samplers are of this variety (14, 17, 19). A simple and inexpensive pneumatic sampler was recently described by Gillham (20). The device (Fig. 3) consists of a disposable 50 mL plastic syringe modified by sawing off the plunger and the finger grips. The syringe is then attached to a gas-line by means of a rubber stopper assembly. The gas-line extends to the surface, and is used to drive the stem-less plunger, and to raise and lower the syringe into the hole. When the gas-line is pressurized, the rubber plunger is held at the tip of the syringe. The sampler is then lowered into the installation, and when the desired depth is reached, the pressure in the gas-line is reduced to atmospheric (or slightly less) and water enters the syringe. The sampler is then retrieved from the installation and the syringe detached from the gas-line. After the tip is sealed, the syringe is used as a short-term storage container. A number

of thief or messenger devices are available in various materials and shapes.

#### 6.1.2 Suction Lift Pumps:

6.1.2.1 Three types of suction lift pumps are the direct line, centrifugal, and peristaltic. A major disadvantage of any suction pump is that it is limited in its ability to raise water by the head available from atmospheric pressure. Thus, if the surface of the water is more than about 25 ft below the pump, water may not be withdrawn. The theoretical suction limit is about 34 ft, but most suction pumps are capable of maintaining a water lift of only 25 ft or less.

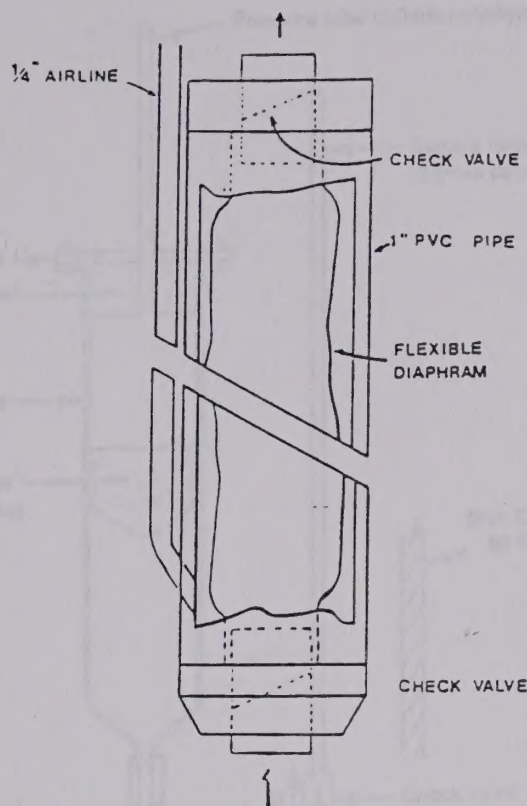
6.1.2.2 Many suction pumps draw the water through some sort of volute in which impellers, pistons, or other devices operate to induce a vacuum. Such pumps are probably unacceptable for most sampling purposes because they are usually constructed of common materials such as brass or mild steel and may expose samples to lubricants. They often induce very low pressures around rotating vanes or other such parts such that degassing or even cavitation may occur. They can mix air with the sample via small leaks in the casing, and they are difficult to adequately clean between uses. Such pumps are acceptable for purging of wells, but should not generally be used for sampling.

6.1.2.3 One exception to the above statements is a peristaltic pump. A peristaltic pump is a self-priming, low volume suction pump which consists of a rotor with ball bearing rollers (21). Flexible tubing is inserted around the pump rotor and squeezed by heads as they revolve in a circular pattern around the rotor. One end of the tubing is placed into the well while the other end can be connected









NOTE—Taken from Ref (4).

FIG. 7 Bladder Pump

directly to a receiving vessel. As the rotor moves, a reduced pressure is created in the well tubing and an increased pressure (<40 psi) on the tube leaving the rotor head. A drive shaft connected to the rotor head can be extended so that multiple rotor heads can be attached to a single drive shaft.

6.1.2.4 The peristaltic pump moves the liquid totally within the sample tube. No part of the pump contacts the liquid. The sample may still be degassed (cavitation is unlikely) but the problems due to contact with the pump mechanism are eliminated. Peristaltic pumps do require a fairly flexible section of tubing within the pumphead itself. A section of silicone tubing is commonly used within the peristaltic pumphead, but other types of tubing can be used particularly for the sections extending into the well or from the pump to the receiving container. The National Council of the Paper Industry for Air and Stream Improvement (22) recommends using medical grade silicone tubing for organic sampling purposes as the standard grade uses an organic vulcanizing agent which has been shown to leach into samples. Medical grade silicone tube is, however, limited to use over a restricted range of ambient temperatures. Various manufacturers offer tubing lined with TFE-fluorocarbon or Viton<sup>3</sup> for use with their pumps. Gibb (1, 8) found little difference between samples withdrawn by a peristaltic pump and those taken by a bailer.

6.1.2.5 A direct method of collecting a sample by suction consists of lowering one end of a length of plastic tubing into the well or piezometer. The opposite end of the tubing is connected to a two way stopper bottle and a hand held or

mechanical vacuum pump is attached to a second tubing leaving the bottle. A check valve is attached between the two lines to maintain a constant vacuum control. A sample can then be drawn directly into the collection vessel without contacting the pump mechanism (5, 23, 24).

6.1.2.6 A centrifugal pump can be attached to a length of plastic tubing that is lowered into the well. A foot valve is usually attached to the end of the well tubing to assist in priming the tube. The maximum lift is about 4.6 m (15 ft) for such an arrangement (23, 25, 26).

6.1.2.7 Suction pump approaches offer a simple sample retrieval method for shallow monitoring. The direct line method is extremely portable though considerable oxidation and mixing may occur during collection. A centrifugal pump will agitate the sample to an even greater degree although pumping rates of 19 to 151 Lpm (5 to 40 gpm) can be attained. A peristaltic pump provides a lower sampling rate with less agitation than the other two pumps. The withdrawal rate of peristaltic pumps can be carefully regulated by adjustment of the rotor head revolution.

6.1.2.8 All three systems can be specially designed so that the water sample contacts only the TFE fluorocarbon or silicone tubing prior to sample bottle entry. Separate tubing is recommended for each well or piezometer sampled.

#### 6.1.3 Electric Submersible Pumps:

6.1.3.1 A submersible pump consists of a sealed electric motor that powers a piston or helical single thread worm at a high rpm. Water is brought to the surface through an access tube. Such pumps have been used in the water well industry for years and many designs exist (5, 26).

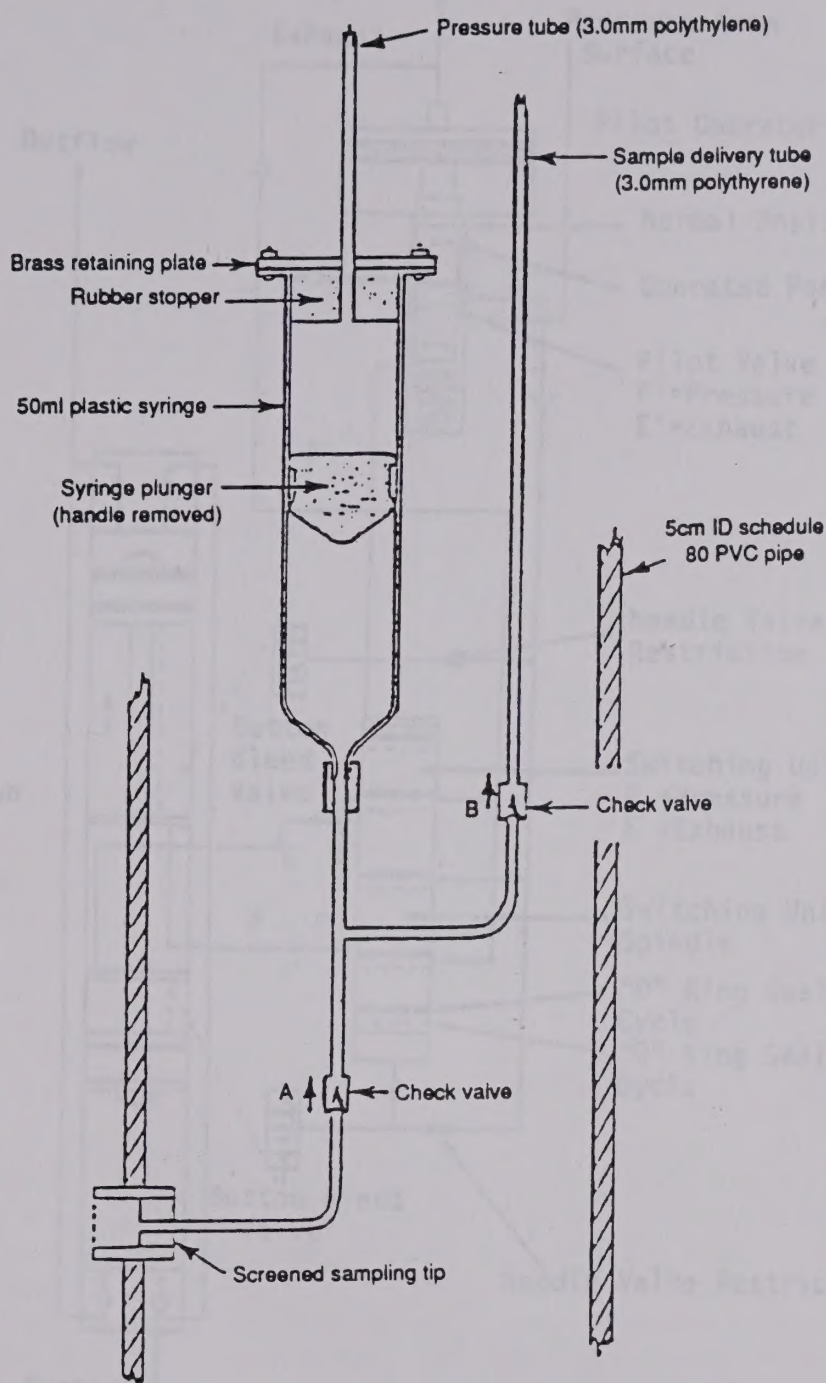
6.1.3.2 Submersible pumps provide relatively high discharge rates for water withdrawal at depths beyond suction

<sup>3</sup> Viton is a trademark of E. I. du Pont de Nemours & Co., Wilmington, DE 19898 and has been found suitable for this purpose.









NOTE—Taken from Ref (48).

FIG. 8 Positive Displacement Syringe Pump

lift capabilities. A battery operated unit 3.6 cm (1.4 in.) in diameter and with a 4.5 Lpm (1.2 gpm) flow rate at 33.5 m (110 ft) has been developed (27). Another submersible pump has an outer diameter of 11.4 cm (4.5 in.) and can pump water from 91 m (300 ft). Pumping rates vary up to 53.0 Lpm (14 gpm) depending upon the depth of the pump (28).

6.1.3.3 A submersible pump provides higher extraction rates than many other methods. Considerable sample agitation results, however, in the well and in the collection tube during transport. The possibility of introducing trace metals into the sample from pump materials also exists. Steam cleaning of the unit followed by rinsing with unchlorinated, deionized water is suggested between sampling when analysis for organics in the parts per million (ppm) or parts per billion (ppb) range is required (29).

#### 6.1.4 Gas-Lift Pumps:

6.1.4.1 Gas-lift pumps use compressed air to bring a water sample to the surface. Water is forced up an eductor pipe that may be the outer casing or a smaller diameter pipe inserted into the well annulus below the water level (30, 31).

6.1.4.2 A similar principle is used for a unit that consists of a small diameter plastic tube perforated in the lower end. This tube is placed within another tube of slightly larger diameter. Compressed air is injected into the inner tube; the air bubbles through the perforations, thereby lifting the water sample via the annulus between the outer and inner tubing (32). In practice, the eductor line should be submerged to a depth equal to 60 % of the total submerged eductor length during pumping (26). A 60 % ratio is considered optimal although a 30 % submergence ratio is adequate.



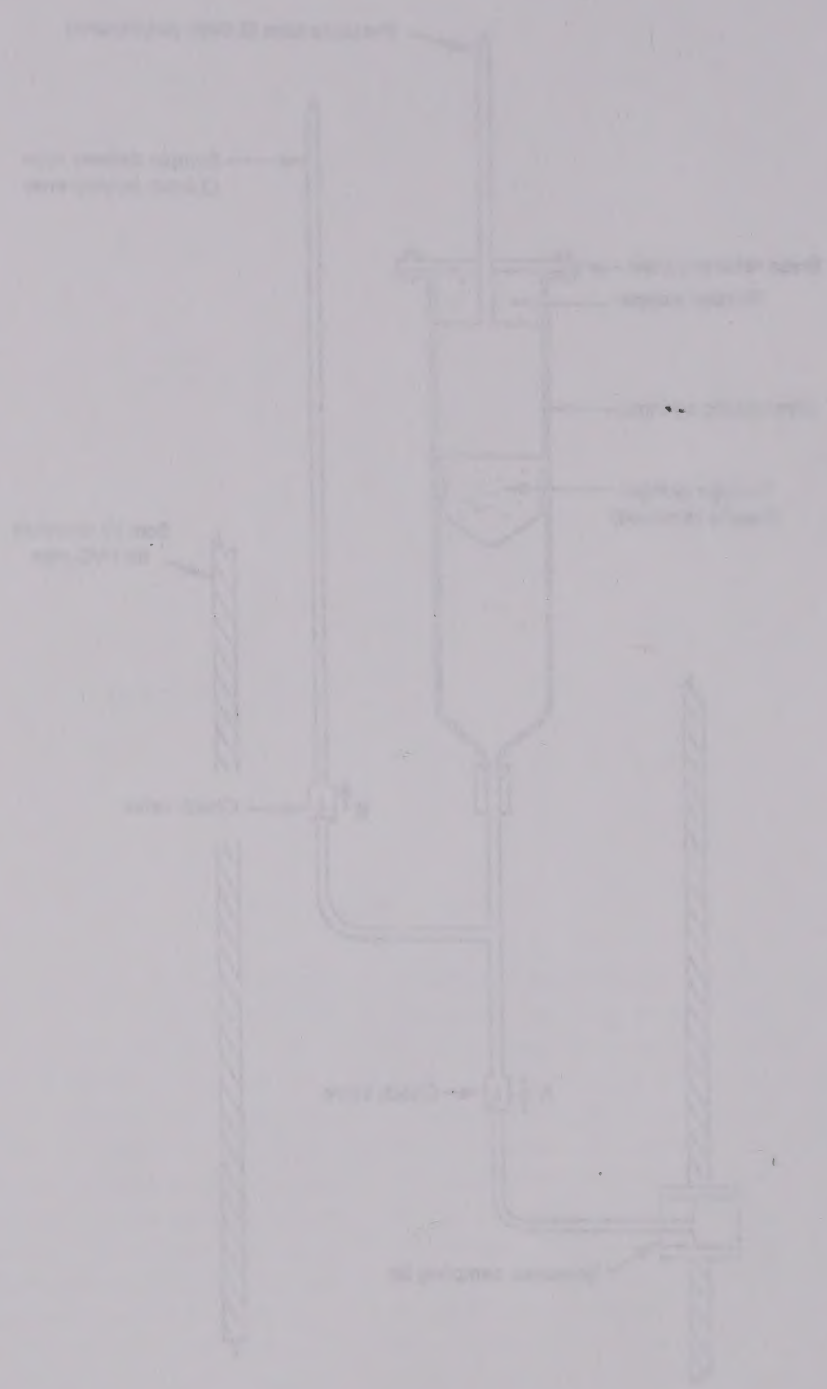
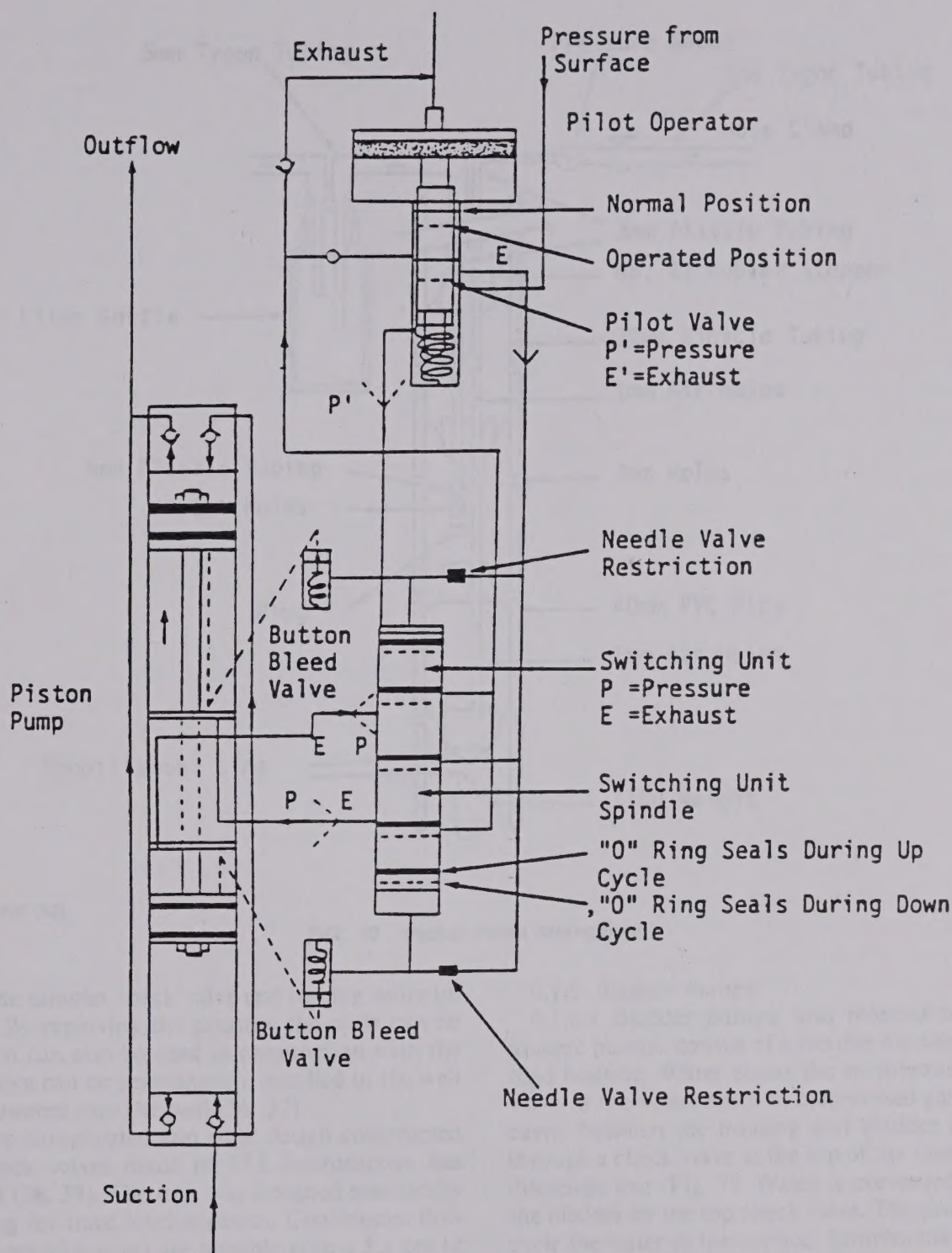


Fig. 1. Schematic diagram of a well system.

of the well system. The well system is shown in Fig. 1. The well system consists of a well casing, a packer, a wellbore, a flowline, a flowmeter, and a wellhead. The well casing is a vertical pipe that runs from the surface down to the wellbore. The packer is a device that seals the well casing against the wellbore. The wellbore is the opening in the earth that allows the well casing to be installed. The flowline is a pipe that carries the fluid from the wellbore to the flowmeter. The flowmeter is a device that measures the flow rate of the fluid. The wellhead is a device that connects the well casing to the flowline.

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NOTE—Taken from Ref (49).

FIG. 9 Gas Driven Piston Pump

6.1.4.3 The source of compressed gas may be a hand pump for depths generally less than 7.6 m (25 ft). For greater depths, air compressors, pressurized air bottles, and air compressed from an automobile engine have been used.

6.1.4.4 As already mentioned, gas-lift methods result in considerable sample agitation and mixing within the well, and cannot be used for samples which will be tested for volatile organics. The eductor pipe or weighted plastic tubing is a potential source of sample contamination. In addition, Gibb (8) uncovered difficulties in sampling for inorganics. These difficulties were attributed to changes in redox, pH,

and species transformation due to solubility constant changes resulting from stripping, oxidation, and pressure changes.

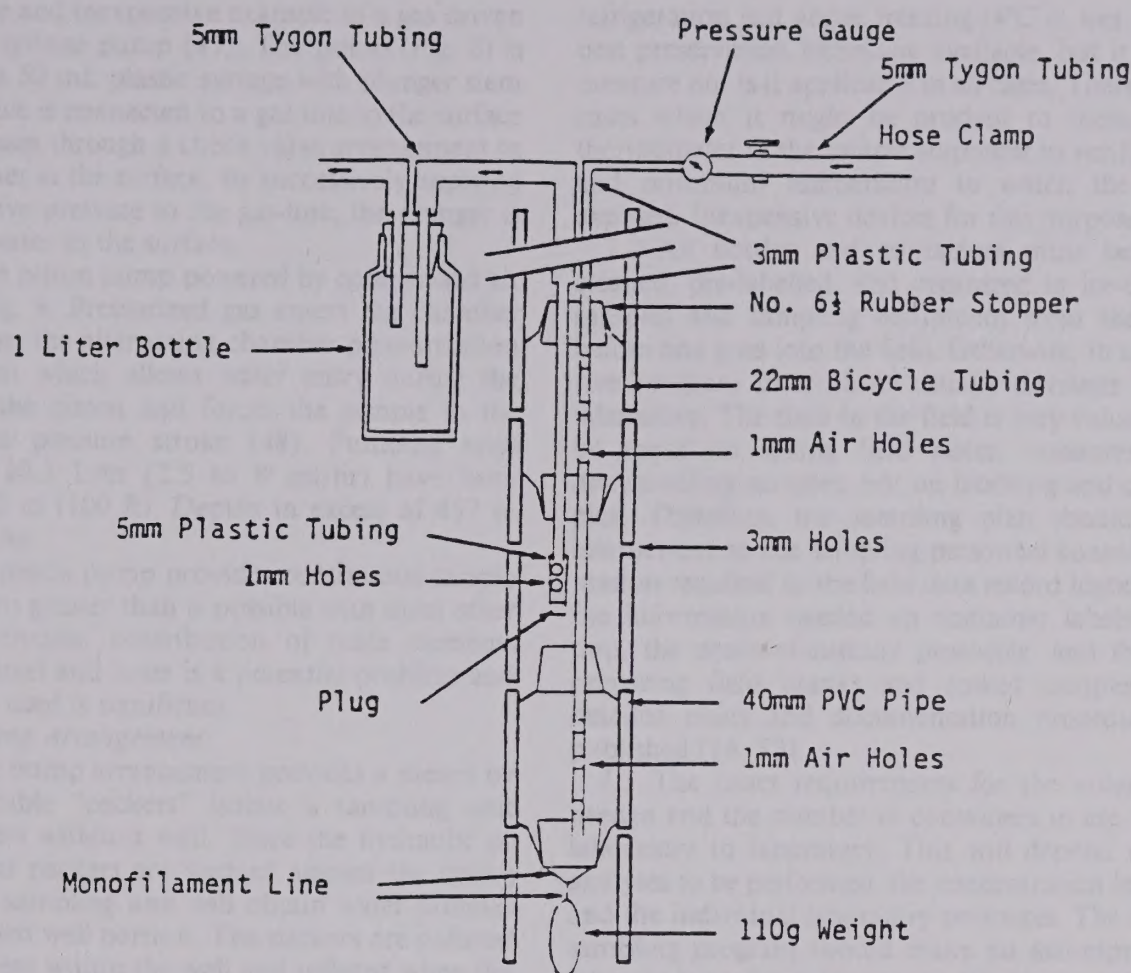
#### 6.1.5 Gas Displacement Pumps:

6.1.5.1 Gas displacement or gas drive pumps are distinguished from gas-lift pumps by the method of sample transport. Gas displacement pumps force a discrete column of water to the surface via mechanical lift without extensive mixing of the pressurized gas and water as occurs with air-lift equipment. The principle is shown schematically in Fig. 4. Water fills the chamber. A positive pressure is applied to the









NOTE—Taken from Ref (53).

FIG. 10 Packer Pump Arrangement

gas line closing the sampler check valve and forcing water up the sample line. By removing the pressure the cycle can be repeated. Vacuum can also be used in conjunction with the gas (30). The device can be permanently installed in the well (33, 34, 35) or lowered into the well (36, 37).

6.1.5.2 A more complicated two stage design constructed of glass with check valves made of TFE-fluorocarbon has been constructed (38, 39). The unit was designed specifically for sample testing for trace level organics. Continuous flow rates up to 2.3 Lpm (0.6 gpm) are possible with a 5.1 cm (2 in.) diameter unit.

6.1.5.3 Gas displacement pumps have also been developed with multiple functions. The water sample in Fig. 5 provides piezometric data measurements with an internally mounted transducer (40). A sample with its transducer exposed externally for piezometric measurements is illustrated in Fig. 6 (41). The sensor can activate the gas source at the surface to cause sample chamber pressurization at the predetermined depth. Another design can be used as a water sampler or as a tool for injecting brine or other tracers into a well (42).

6.1.5.4 Gas displacement pumps offer reasonable potential for preserving sample integrity because little of the driving gas comes in contact with the sample as the sample is conveyed to the surface by a positive pressure. There is, however, a potential loss of dissolved gasses or contamination from the driving gas and the housing materials.

#### 6.1.6 Bladder Pumps:

6.1.6.1 Bladder pumps, also referred to as gas-operated squeeze pumps, consist of a flexible membrane enclosed by a rigid housing. Water enters the membrane through a check valve in the vessel bottom; compressed gas injected into the cavity between the housing and bladder forces the sample through a check valve at the top of the membrane and into a discharge line (Fig. 7). Water is prevented from re-entering the bladder by the top check valve. The process is repeated to cycle the water to the surface. Samples taken from depths of 30.5 m (100 ft) have been reported.

6.1.6.2 A variety of design modifications and materials are available (43, 44). Bladder materials include neoprene, rubber, ethylene propylene terpolymer (E.P.T.), nitrile, and the fluorocarbon Viton.<sup>3</sup> A bladder made of TFE-fluorocarbon is also under development (45). Automated sampling systems have been developed to control the time between pressurization cycles (46).

6.1.6.3 Bladder pumps provide an adaptable sampling tool due primarily to the number of bladder shapes that are feasible. These devices have a distinct advantage over gas displacement pumps in that there is no contact with the driving gas. Disadvantages include the large gas volumes required, low pumping rates, and potential contamination from many of the bladder materials, the rigid housing, or both.

#### 6.1.7 Gas Driven Piston Pumps:







6.1.7.1 A simple and inexpensive example of a gas driven piston pump is a syringe pump (47). The pump (Fig. 8) is constructed from a 50 mL plastic syringe with plunger stem removed. The device is connected to a gas line to the surface and the sample passes through a check valve arrangement to a sampling container at the surface. By successively applying positive and negative pressure to the gas-line, the plunger is activated driving water to the surface.

6.1.7.2 A double piston pump powered by compressed air is illustrated in Fig. 9. Pressurized gas enters the chamber between the pistons; the alternating chamber pressurization activates the piston which allows water entry during the suction stroke of the piston and forces the sample to the surface during the pressure stroke (48). Pumping rates between 9.5 and 30.3 L/hr (2.5 to 8 gal/hr) have been reported from 30.5 m (100 ft). Depths in excess of 457 m (1500 ft) are possible.

6.1.7.3 The gas piston pump provides continuous sample withdrawal at depths greater than is possible with most other approaches. Nevertheless, contribution of trace elements from the stainless steel and brass is a potential problem and the quantity of gas used is significant.

#### 6.1.8 Packer Pump Arrangement:

6.1.8.1 A packer pump arrangement provides a means by which two expandable "packers" isolate a sampling unit between two packers within a well. Since the hydraulic or pneumatic activated packers are wedged against the casing wall or screen, the sampling unit will obtain water samples only from the isolated well portion. The packers are deflated for vertical movement within the well and inflated when the desired depth is attained. Submersible, gas lift, and suction pumps can be used for sampling. The packers are usually constructed from some type of rubber or rubber compound (48, 49, 50, 51). A packer pump unit consisting of a vacuum sampler positioned between two packers is illustrated in Fig. 10 (52).

6.1.8.2 A packer assembly allows the isolation of discrete sampling points within a well. A number of different samplers can be situated between the packers depending upon the analytical specifications for sample testing. Vertical movement of water outside the well casing during sampling is possible with packer pumps but depends upon the pumping rate and subsequent disturbance. Deterioration of the expandable materials will occur with time with the increased possibility of undesirable organic contaminants contributing to the water sample.

## 7. Sample Containers and Preservation

7.1 Complete and unequivocal preservation of samples, whether domestic wastewater, industrial wastes, or natural waters, is practically impossible. At best, preservation techniques only retard the chemical and biological changes that inevitably continue after the sample is removed from the source. Therefore, insuring the timely analysis of a sample should be one of the foremost considerations in the sampling plan schedule. Methods of preservation are somewhat limited and are intended to retard biological action, retard hydrolysis of chemical compounds and complexes, and reduce the volatility of constituents. Preservation methods are generally limited to pH control, chemical addition, refrigeration and freezing. For water samples, immediate

refrigeration just above freezing (4°C in wet ice) is often the best preservation technique available, but it is not the only measure nor is it applicable in all cases. There may be special cases where it might be prudent to include a recording thermometer in the sample shipment to verify the maximum and minimum temperature to which the samples were exposed. Inexpensive devices for this purpose are available.

7.2 All bottles and containers must be specially pre-cleaned, pre-labelled, and organized in ice-chests (isolating samples and sampling equipment from the environment) before one goes into the field. Otherwise, in any comprehensive program utter chaos usually develops in the field or laboratory. The time in the field is very valuable and should be spent on taking field notes, measurements, and in documenting samples, not on labelling and organizing samples. Therefore, the sampling plan should include clear instructions to the sampling personnel concerning the information required in the field data record logbook (notebook), the information needed on container labels for identification, the chain-of-custody protocols, and the methods for preparing field blanks and spiked samples. Example of detailed plans and documentation procedures have been published (14, 53).

7.3 The exact requirements for the volumes of sample needed and the number of containers to use may vary from laboratory to laboratory. This will depend on the specific analyses to be performed, the concentration levels of interest, and the individual laboratory protocols. The manager of the sampling program should make no assumptions about the laboratory analyses. He should discuss the analytical requirements of the sampling program in detail with the laboratory coordinator beforehand. This is especially the case since some analyses and preservation measures must be performed at the laboratory as soon as possible after the samples arrive. Thus, appropriate arrangements must be made.

7.4 There are a number of excellent references available which list the containers and preservation techniques appropriate for water and soils (13, 14, 50, 54, 55, 56). The "Handbook for Sampling and Sample Preservation of Water and Wastewater" is an excellent reference and perhaps the most comprehensive one (14). Some of this information is summarized in Table 1.

7.5 Sample containers for trace organic samples require special cleaning and handling considerations (57). The sample container for purgeable organics consist of a screw-cap vial (25 to 125 mL) fitted with a TFE-fluorocarbon faced silicone septum. The vial is sealed in the laboratory immediately after cleaning and is only opened in the field just prior to pouring sample into it. The water sample then must be sealed into the vial headspace free (no air bubbles) and immediately cooled (4°C) for shipment. Multiple samples (usually about four taken from one large sample container) are taken because leakage of containers may cause losses, may allow air to enter the containers, and may cause erroneous analysis of some constituents. Also, some analyses are best conducted on independent protected samples.

7.6 The purgeable samples must be analyzed by the laboratory within 14 days after collection, unless they are to be analyzed for acrolein or acrylonitrile (in which case they are to be analyzed within 3 days). For samples for solvent extractions (extractable organics-base neutrals, acids and







pesticides), the sample bottles are narrow mouth, screw cap quart bottles or half-gallon bottles that have been precleaned, rinsed with the extracting organic solvent and oven dried at 105°C for at least 1 h. These bottles must be sealed with TFE-fluorocarbon lined caps (Note). Samples for organic extraction must be extracted within 7 days and analyzed within 30 days after extraction. Special pre-cleaned, solvent rinsed and oven-dried stainless steel beakers (one for each monitoring well) may be used for transferring samples from the sampling device to the sample containers.

NOTE—When collecting samples, the bottles should not be overfilled or prerinsed with sample before filling because oil and other materials may remain in the bottle. This can cause erroneously high results.

7.7 For a number of groundwater parameters, the most meaningful measurements are those made in the field at the time of sample collection or at least at an on-site laboratory. These include the water level in the well and parameters that sometimes can change rapidly with storage. A discussion of the various techniques for measuring the water level in the well is contained in a NCASI publication (5) and detailed procedures are outlined in a U.S. Geological Survey publication (58). Although a discussion of these techniques is beyond the scope of this guide, it is important to point out that accurate measurements must be made before a well is flushed or only after it has had sufficient time to recover. Parameters that can change rapidly with storage include specific conductance, pH, turbidity, redox potential, dissolved oxygen, and temperature. For some of the other

parameters, the emphasis in groundwater monitoring is on the concentration of each specific dissolved component, not the total concentration of each. Samples for these types of measurements should be filtered through 0.45 µm membrane filters ideally in the field or possibly at an on-site laboratory as soon as possible. Analyses often requiring filtered samples include all metals, radioactivity parameters, total organic carbon, dissolved orthophosphate (if needed), and total dissolved phosphorous (if needed) (13, 14). If metals are to be analyzed, filter the sample prior to acid preservation. For TOC organics, the filter material should be tested to assure that it does not contribute to the TOC. The type or size of the filter to be used is not well understood. However, if results of metal, TOC or other parameters that could be effected by solids are to be compared, the same filtering procedure must be used in each case. Repeated analytical results should state whether the samples were filtered and how they were filtered.

7.8 Shipment and receipt of samples must be coordinated with the laboratory to minimize time in transit. All samples for organic analysis (and many other parameters), should arrive at the laboratory within one day after it is shipped and be maintained at about 4°C with wet ice. The best way to get them to the laboratory in good condition is to send them in sturdy insulated ice chests (coolers) equipped with bottle dividers. 24-h courier service is recommended, if personal delivery service is not practical.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

















# Standard Guide for Soil Sampling from the Vadose Zone<sup>1</sup>

This standard is issued under the fixed designation D 4700; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This guide addresses procedures that may be used for obtaining soil samples from the vadose zone (unsaturated zone). Samples can be collected for a variety of reasons including the following:

- 1.1.1 Stratigraphic description,
- 1.1.2 Hydraulic conductivity testing,
- 1.1.3 Moisture content measurement,
- 1.1.4 Moisture release curve construction,
- 1.1.5 Geotechnical testing,
- 1.1.6 Soil gas analyses,
- 1.1.7 Microorganism extraction, or
- 1.1.8 Pore liquid and soils chemical analyses.

1.2 This guide focuses on methods that provide soil samples for chemical analyses of the soil or contained liquids or contaminants. However, comments on how methods may be modified for other objectives are included.

1.3 This guide does not describe sampling methods for lithified deposits and rocks (for example, sandstone, shale, tuff, granite).

1.4 In general, it is prudent to perform all field work with at least two people present. This increases safety and facilitates efficient data collection.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

- D 420 Practice for Investigating and Sampling Soil and Rock for Engineering Purposes<sup>2</sup>
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
- D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils<sup>2</sup>

D 1587 Method for Thin-Walled Tube Sampling of Soils<sup>2</sup>

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>2</sup>

D 2607 Classification of Peats, Mosses, Humus, and Related Products<sup>2</sup>

D 3550 Method for Ring-Lined Barrel Sampling of Soils<sup>2</sup>

D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)<sup>2</sup>

D 4220 Practice for Preserving and Transporting Soil Samples<sup>2</sup>

## 3. Terminology

### 3.1 Definitions:

3.1.1 Except where noted, all terms and symbols in this guide are in accordance with the following publications. In order of consideration they are:

3.1.1.1 Terminology D 653.

3.1.1.2 *Compilation of ASTM Standard Terminology*,<sup>3</sup> and

3.1.1.3 *Webster's New Collegiate Dictionary*.<sup>4</sup>

3.1.2 For definitions and classifications of soil related terms used, refer to Practice D 2488 and Terminology D 653. Additional terms that require clarification are defined in 3.2.

### 3.2 Descriptions of Terms Specific to This Standard:

3.2.1 *cascading water*—perched ground water that enters a well casing via cracks or uncovered perforations, trickling, or pouring down the inside of the casing.

3.2.2 *sludge*—a water charged sedimentary deposit.

3.2.2.1 *Discussion*—The water-formed sedimentary deposit may include all suspended solids carried by the water and trace elements that were in solution in the water. Sludge usually does not cohere sufficiently to retain its physical shape when mechanical means are used to remove it from the surface on which it deposits, but it may be baked in place and be adherent.

## 4. Summary of Guide

4.1 Sampling vadose zone soil involves inserting into the ground a device that retains and recovers a sample. Devices and systems for vadose zone sampling are divided into two general groups, namely the following: samplers used in conjunction with hand operated devices; and samplers used

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.08.

<sup>3</sup> *Compilation of ASTM Standard Terminology*, Sixth edition, ASTM, 1916 Race St., Phila., PA 19103, 1986.

<sup>4</sup> *Webster's New Collegiate Dictionary*, Fifth edition, \_\_\_\_\_ 1977.



# Standard Guide for Soil Sampling from the Vadose Zone<sup>1</sup>

This standard is a revision of the 1990 edition, Designation D 4700-90. The previous edition, Designation D 4700-80, was approved by the American Society of Civil Engineers (ASCE) in 1980. The previous edition, Designation D 4700-70, was approved by the American Society of Civil Engineers (ASCE) in 1970. The previous edition, Designation D 4700-60, was approved by the American Society of Civil Engineers (ASCE) in 1960. The previous edition, Designation D 4700-50, was approved by the American Society of Civil Engineers (ASCE) in 1950. The previous edition, Designation D 4700-40, was approved by the American Society of Civil Engineers (ASCE) in 1940. The previous edition, Designation D 4700-30, was approved by the American Society of Civil Engineers (ASCE) in 1930. The previous edition, Designation D 4700-20, was approved by the American Society of Civil Engineers (ASCE) in 1920. The previous edition, Designation D 4700-10, was approved by the American Society of Civil Engineers (ASCE) in 1910. The previous edition, Designation D 4700-00, was approved by the American Society of Civil Engineers (ASCE) in 1900.

- D 1586 Standard Test Method for Determining the Permeability of Soils
- D 1587 Method for Thin-Sectioned Soil Sampling
- D 1588 Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 1589 Classification of Soils: Manual, Visual, and Soils
- D 1590 Method for Ring-Loaded Soil Sampling in Soils
- D 1591 Practice for Description of Soils (Visual-Manual Procedure)
- D 1592 Practice for Describing and Interpreting Soil

## 1. Terminology

### 1.1 Definitions

1.1.1 **Soil**—any solid, semi-solid, or liquid material that is in contact with the atmosphere and is capable of supporting plant life.

1.1.2 **Soil Sampling**—the process of obtaining a sample of soil for analysis.

1.1.3 **Soil Sampling Method**—the procedure used to obtain a sample of soil for analysis.

1.1.4 **Soil Sampling Equipment**—the tools and devices used to obtain a sample of soil for analysis.

1.1.5 **Soil Sampling Procedure**—the sequence of steps used to obtain a sample of soil for analysis.

1.1.6 **Soil Sampling Results**—the data obtained from a soil sampling procedure.

1.1.7 **Soil Sampling Report**—the document that contains the results of a soil sampling procedure.

1.1.8 **Soil Sampling Record**—the document that contains the details of a soil sampling procedure.

1.1.9 **Soil Sampling Log**—the document that contains the dates and times of soil sampling procedures.

1.1.10 **Soil Sampling Map**—the document that contains the locations of soil sampling procedures.

1.1.11 **Soil Sampling Data**—the information obtained from a soil sampling procedure.

1.1.12 **Soil Sampling Analysis**—the process of determining the properties of a soil sample.

1.1.13 **Soil Sampling Interpretation**—the process of determining the meaning of soil sampling results.

1.1.14 **Soil Sampling Quality Assurance**—the process of ensuring the accuracy and reliability of soil sampling results.

1.1.15 **Soil Sampling Quality Control**—the process of ensuring the consistency and repeatability of soil sampling results.

1.1.16 **Soil Sampling Standard**—the document that defines the requirements for soil sampling procedures.

1.1.17 **Soil Sampling Procedure**—the sequence of steps used to obtain a sample of soil for analysis.

1.1.18 **Soil Sampling Equipment**—the tools and devices used to obtain a sample of soil for analysis.

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1.1.26 **Soil Sampling Analysis**—the process of determining the properties of a soil sample.

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1.1.41 **Soil Sampling Interpretation**—the process of determining the meaning of soil sampling results.



Type of Sampler	Obtain Core Sample		Most Suitable Core Types		Operation in Saturated Soils		Most Suitable Soil Moisture Conditions		Access to Sample Sites During Poor Soil Conditions		Retrieve Sample Bulk		Labor Required	
	Yes	No	Core	Can/No	Fav	Unfav	Wet	Dry	Wet	Dry	Sh	Lp	Eng	Others
<b>A. Drill Rig Samplers</b>														
1. Multipurpose Drill Rig	•		•	•	•		•	•	•	•	•	•	•	
2. Split-barrel Drive Sampler	•		•		•		•			•			•	
3. Thin-Walled Tube Sampler	•		•			•	•	•	•	•	•	•	•	
4. Piston Sampler	•		•			•	•			•			•	
5. Continuous Section Tube system	•		•		•		•	•	•		•		•	
6. Hand-Held Power Auger	•				•					•			•	
<b>B. Hand Operated Samplers</b>														
1. Screw-Type Auger		•				•	•			•			•	
2. Barrel Auger														
a. Post Hole Auger		•	•			•				•			•	
b. Dutch Auger		•				•								
c. Regular Barre Auger		•	•			•				•			•	
d. Sand Auger		•		•		•				•			•	
e. Mud Auger		•	•			•				•			•	
3. Tube-Type Sampler														
a. Bed Sampling Tube														
(1) Wet To		•				•	•			•			•	
(2) Dry To		•				•	•			•			•	
b. Verwey-type Tube		•											•	

FIG. 1 Criteria for Selecting Soil Sampling Equipment

in conjunction with multipurpose or auger drill rigs. This guide discusses these groups and their associated practices.

4.2 The discussion of each device is organized into three sections, describing the device, describing sampling methods, and limitations and advantages of its use.

4.3 This guide identifies and describes a number of sampling methods and samplers. It is advisable to consult available site-specific geological and hydrological data to assist in determining the sampling method and sampler best suited for a specific project. It is also advisable to contact a local firm providing the services required as not all sampling and drilling methods described in this guide are available nationwide.

## 5. Significance and Use

5.1 Chemical analyses of liquids, solids, and gases from the vadose zone can provide information on the presence, possible source, migration route, and physical-chemical behavior of contaminants. Remedial or mitigating measures can be formulated based on this information. This guide describes devices and procedures that can be used to obtain vadose zone soil samples.

5.2 Soil sampling is useful for the reasons presented in Section 1. However, it should be recognized that the general method is destructive, and that resampling at an exact location is not possible. Therefore, if a long term monitoring program is being designed, other methods for obtaining samples should be considered.

## 6. Criteria for Selecting Soil Samplers

6.1 Important criteria to consider when selecting devices for vadose zone soil sampling include the following:

6.1.1 Type of sample: An encased core sample, an uncased core sample, a depth-specific representative sample, or a sample according to requirements of the analyses,

6.1.2 Sample size requirements,

6.1.3 Suitability for sampling various soil types,

6.1.4 Maximum sampling depth,

6.1.5 Suitability for sampling soils under various moisture conditions,

6.1.6 Ability to minimize cross contamination,

6.1.7 Accessibility to the sampling site, and

6.1.8 Personnel requirements.

6.2 The sampling devices described in this guide have been evaluated for these criteria. The results are summarized in Fig. 1.

## 7. Sampling with Hand Operated Devices

7.1 These devices, that have mostly been developed for agricultural purposes, include:

7.1.1 Screw-type augers,

7.1.2 Barrel augers,

7.1.3 Tube-type samplers,

7.1.4 Hand held power augers, and

7.1.5 Trench sampling with shovels in conjunction with machine excavations.

7.2 The advantages of using hand operated devices over drill rigs are the ease of equipment transport to locations with poor vehicle access, and the lower costs of setup and decontamination. However, a major disadvantage is that these devices are limited to shallower depths than drill rigs.

### 7.3 Screw-Type Augers:

7.3.1 *Description*—The screw or ship auger is essentially a small diameter (for example, 1.5 in. (3.81 cm)) wood auger from which the cutting side flanges and tip have been removed (1)<sup>5</sup> (see Fig. 2(a)). According to the Soil Survey Staff (1), the spiral part of the auger should be about 7 in. (18 cm) long, with the distances between flights about the same as the diameter (for example, 1.5 in.) of the auger. This facilitates measuring the depth of penetration of the tool. Variations on this design include the closed spiral auger and the Jamaica open spiral auger (2) (see Fig. 2(b) and 1(c)). The

<sup>5</sup> The boldface numbers in parentheses refer to the list of references at the end of the text.







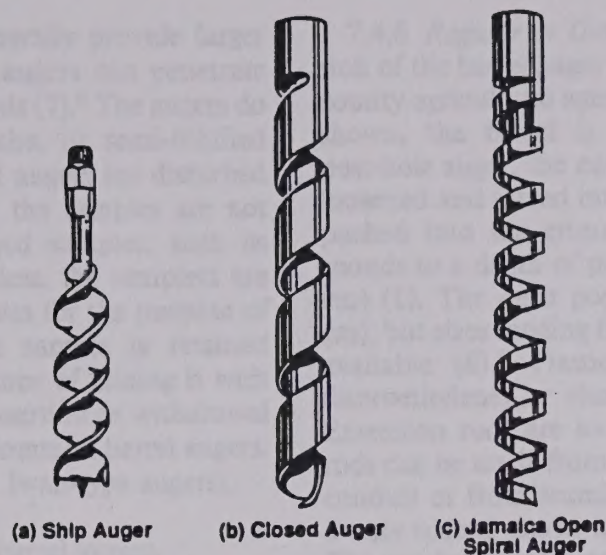


FIG. 2 Screw Type Augers

auger is welded onto a length of solid or tubular rod. The upper end of this rod is threaded, to accept a handle or extension rods. As many extensions are used as are required to reach the target sampling depth. The rod and the extensions are marked in even increments (for example, in 6-in. (15.24-cm) increments) above the base of the auger to aid in determining drilling depth. A wooden or metal handle fits into a tee-type coupling, screwed into the uppermost extension rod.

**7.3.2 Sampling Method**—For drilling, the auger is rotated manually. The operator may have to apply downward pressure to start and embed the auger; afterwards, the auger screws itself into the soil. The auger is advanced to its full length, and then pulled up and removed. Soil from the deepest interval penetrated by the auger is retained on the auger flights. A sample can be collected from the flights using a spatula. A foot pump operated hydraulic system has been developed to advance augers up to 4.5 in. (11.43 cm) in diameter. This larger diameter allows insertion of other sampling devices into the drill hole, once the auger is removed, if desired (3).<sup>6</sup>

**7.3.3 Comments**—Samples obtained with screw-type samplers are disturbed and are not truly core samples. Therefore, the samples are not suitable for tests requiring undisturbed samples, such as hydraulic conductivity tests. In addition, soil structures are disrupted and small scale lithologic features cannot be examined. Nevertheless, screw-

type samplers are still suitable for use in collecting samples for the purpose of detecting contaminants. However, it is difficult to avoid transporting shallow soils downward when reentering a drill hole. When representative samples are desired from a discrete interval, the borehole must be made large enough to insert a sampler and extend it to the bottom of the borehole without touching the sides of the borehole. It is suggested that a larger diameter auger be used to advance and clear the borehole, then a smaller diameter auger sampler be used to obtain the sample. Screw-type augers work better in wet, cohesive soils than in dry, loose soils. Sampling in very dry (for example, powdery) soils may not be possible with these augers as soils will not be retained on the auger flights. Also, if the soil contains gravel or rock fragments larger than about one tenth of the hole diameter, drilling may not be possible (4).

#### 7.4 Barrel Augers:

**7.4.1 Description**—The barrel auger consists of a bit with cutting edges welded to a short tube or barrel within which the soil sample is retained, welded in turn to shanks. The shanks are welded to a threaded rod at the other end. Extension rods are attached as required to reach the target sampling depth. Extensions are marked in increments above the base of the tool. The uppermost extension rod contains a tee-type coupling for a handle. The auger is available in carbon steel and stainless steel with hardened steel cutting edges (5, 6).

**7.4.2 Sampling Method**—The auger is rotated to advance the barrel into the ground. The operator may have to apply downward pressure to keep the auger advancing. When the barrel is filled, the unit is withdrawn from the soil cavity and a sample may be collected from the barrel.

<sup>6</sup> This reference is manufacturer's literature, and it has not been subjected to technical review.



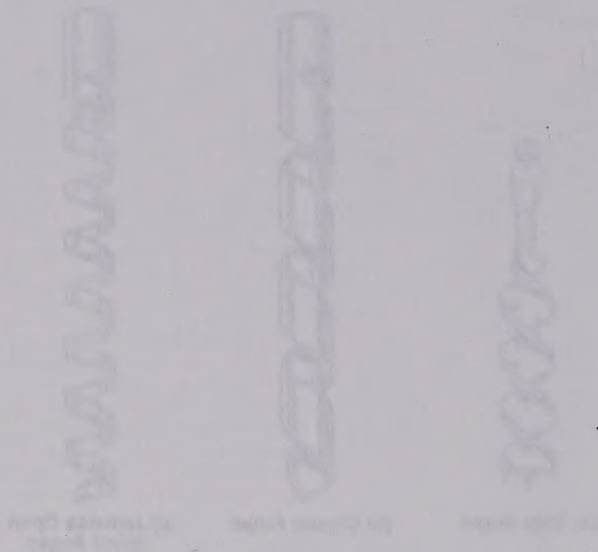


FIG. 1. Three types of augers.

type augers are still useful for use in collecting samples for the purpose of determining soil moisture. However, it is difficult to avoid undesirable shallow soil samples when using a hand auger. When representative samples are desired from a greater depth, the use of a power auger is recommended. The power auger is used in the bottom of the hole without touching the side of the hole. It is important that a large diameter auger be used to advance and clear the hole, then a smaller diameter auger can be used to obtain the sample. The power auger works better in wet, cohesive soils than in dry, loose soils. Sampling in very dry (or sandy, powdery) soils may not be possible with these augers as soil will not be retained in the auger flights. Also, if the soil contains gravel or rock fragments larger than about one third of the hole diameter, drilling may not be possible.

#### 1.2. Power Auger

1.2.1. Description—The power auger consists of a 2 1/2 inch diameter shaft welded to a short tube or barrel which is the tool auger. The tool auger is twisted, welded to the shaft, and the shaft is twisted to a diameter of 1 1/2 inches. The power auger is used in the bottom of the hole without touching the side of the hole. It is important that a large diameter auger be used to advance and clear the hole, then a smaller diameter auger can be used to obtain the sample. The power auger works better in wet, cohesive soils than in dry, loose soils. Sampling in very dry (or sandy, powdery) soils may not be possible with these augers as soil will not be retained in the auger flights. Also, if the soil contains gravel or rock fragments larger than about one third of the hole diameter, drilling may not be possible.

#### 1.2.2. Sampling Method

The power auger is used in the bottom of the hole without touching the side of the hole. It is important that a large diameter auger be used to advance and clear the hole, then a smaller diameter auger can be used to obtain the sample. The power auger works better in wet, cohesive soils than in dry, loose soils. Sampling in very dry (or sandy, powdery) soils may not be possible with these augers as soil will not be retained in the auger flights. Also, if the soil contains gravel or rock fragments larger than about one third of the hole diameter, drilling may not be possible.

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1.2.3. Sampling Method—For drilling the power auger is used in the bottom of the hole without touching the side of the hole. It is important that a large diameter auger be used to advance and clear the hole, then a smaller diameter auger can be used to obtain the sample. The power auger works better in wet, cohesive soils than in dry, loose soils. Sampling in very dry (or sandy, powdery) soils may not be possible with these augers as soil will not be retained in the auger flights. Also, if the soil contains gravel or rock fragments larger than about one third of the hole diameter, drilling may not be possible.

1.2.4. Comments—The power auger is used in the bottom of the hole without touching the side of the hole. It is important that a large diameter auger be used to advance and clear the hole, then a smaller diameter auger can be used to obtain the sample. The power auger works better in wet, cohesive soils than in dry, loose soils. Sampling in very dry (or sandy, powdery) soils may not be possible with these augers as soil will not be retained in the auger flights. Also, if the soil contains gravel or rock fragments larger than about one third of the hole diameter, drilling may not be possible.

\* The power auger is recommended for use in wet, cohesive soils.



**7.4.3 Comments**—Barrel augers generally provide larger samples than screw-type augers. The augers can penetrate shallow clays, silts, and fine grained sands (7).<sup>6</sup> The augers do not work well in gravelly soils, caliche, or semi-lithified deposits. Samples obtained with barrel augers are disturbed and are not core samples. Therefore, the samples are not suitable for tests requiring undisturbed samples, such as hydraulic conductivity tests. Nevertheless, the samplers are still suitable for use in collecting samples for the purpose of detecting contaminants. Because the sample is retained inside the barrel, there is less of a chance of mixing it with soil from a shallower interval during insertion or withdrawal of the sampler. The following are five common barrel augers:

- 7.4.3.1 Post-hole augers (also called Iwan-type augers),
- 7.4.3.2 Dutch-type augers,
- 7.4.3.3 Regular or general purpose barrel augers,
- 7.4.3.4 Sand augers, and
- 7.4.3.5 Mud augers.

**7.4.4 Post-Hole Augers**—The most readily available barrel auger is the post-hole auger (also called the Iwan-type auger) (8). As shown in Fig. 3, the barrel consists of two-part cylindrical leaves rather than a complete cylinder and is slightly tapered toward the cutting bit. The taper and the cupped bit help to retain soils within the barrel. The barrel is available with a 3 to 12-in. (7.62 to 30.48-cm) diameter. There are two types of drilling systems, one has a single rod and handle, and the other has two handles. In stable, cohesive soils, the auger can be advanced up to 25 ft (7.62 m) (8).

**7.4.5 Dutch-Type Augers**—The Dutch-type auger (commercially developed by Eijkelkamp) is a smaller variation of the post-hole auger design. As shown in Fig. 4, the pointed bit is continuous with two, narrow part-cylindrical barrel segments, welded onto the shanks. The barrel generally has a 3 in. (7.62 cm) outside diameter. This tool is best suited for sampling wet, clayey soils.

**7.4.6 Regular or General Purpose Barrel Augers**—A version of the barrel auger commonly used by soil scientists and county agricultural agents is depicted in Fig. 5(a) and (b). As shown, the barrel is a complete cylinder. As with the post-hole auger, the cutting blades are cupped so that soil is loosened and forced into the barrel as the unit is rotated and pushed into the ground. Each filling of the barrel corresponds to a depth of penetration of 3 to 5 in. (7.62 to 12.70 cm) (1). The most popular barrel diameter is 3.5 in. (8.89 cm), but sizes ranging from 1.5 to 7 in. (3.81 to 17.78 cm) are available (6).<sup>6</sup> Plastic, stainless steel, PTFE (polytetrafluoroethylene) or aluminum liners can also be used (6).<sup>6</sup> Extension rods are available in 4 ft (1.22 m) lengths. The rods can be made from standard black pipe, from lightweight conduit or from seamless steel tubing. The extensions have evenly spaced marks to facilitate determining sample depth. The regular barrel auger is suitable for use in loam type soils.

**7.4.7 Sand Augers**—For dry, sandy soils it may be necessary to use a variation of the regular barrel auger that includes a specially-formed bit to retain the sample in the barrel (see Fig. 5(c)). Sand augers with 2, 3, or 4-in. (5.08, 7.62, or 10.16-cm) diameters are available (5).<sup>6</sup>

**7.4.8 Mud Augers**—Another variation on the regular barrel auger design is available for sampling wet, clayey soils. As shown in Fig. 5(d), the barrel is designed with open sides to facilitate extraction of samples. The bits are the same as those used on the regular barrel auger (6).<sup>6</sup> Mud augers with 2, 3, or 4-in. (5.08, 7.62, or 10.16-cm) diameters are available (5).<sup>6</sup>

#### 7.5 Tube-Type Samplers:

**7.5.1 Tube-type samplers** generally have proportionally smaller diameters and greater body lengths than those of barrel augers.

**7.5.2** For sampling, these units are perched into the soil causing the tube to fill with material from the interval penetrated. The assembly is then pulled to the surface and a sample can be collected from the tube. Since the device is not

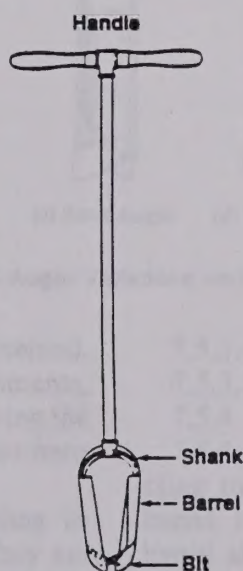


FIG. 3 Post-Hole Type Barrel Auger







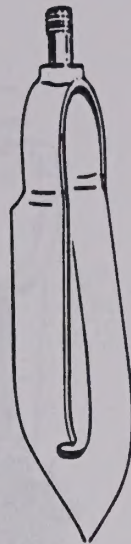
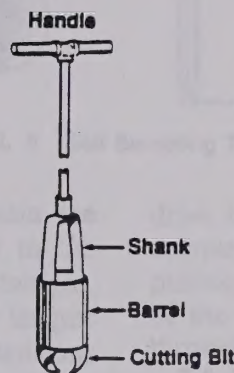
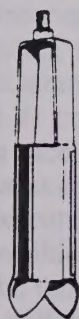


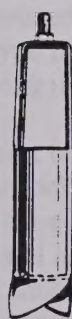
FIG. 4 Dutch Type Auger



(a) Regular Barrel Auger



(b) Regular Barrel Auger



(c) Sand Auger



(d) Mud Auger

FIG. 5 Barrel Auger Variations and Soil Moisture

rotated, a nearly undisturbed sample can be obtained. Commercial units are available with foot lever attachments, a hydraulic apparatus, or drop-hammers to aid in driving the sampler into the ground (5)<sup>6</sup>. Vibratory heads have also been developed to advance tube-type samplers (9).<sup>6</sup>

7.5.3 These units are not as suitable for sampling in compacted, gravelly soils as are the barrel augers. They are preferred if an undisturbed sample is required. Commonly used varieties of the tube type samplers include:

7.5.3.1 Soil sampling tubes (also called Lord samplers),

7.5.3.2 Veihmeyer tubes (also called King tubes),

7.5.3.3 Thin-walled tube samplers (also called Shelby tubes),

7.5.3.4 Ring-lined barrel samplers, and

7.5.3.5 Piston samplers.

7.5.4 Soil Sampling Tubes:

7.5.4.1 Description—As depicted in Fig. 6, the soil sampling tube consists of a hardened cutting tip, a cut-away barrel, and an uppermost threaded segment. The cut-away barrel allows textural examination and easy removal of soil samples. Generally, the tube is constructed from high strength alloy steel (10).<sup>6</sup> The samplers are available with 6, 12, 15, 18, and 24-in. (15.24, 30.48, 38.10, 45.72, 60.96-cm) lengths (5, 6). The tubes are available with 1.13 or 0.88-in. (2.87 or 2.22-cm) outside diameter. Two modified versions of the tip are available, for sampling in wet or dry soils. The





FIG. 1. Seedling Type A



FIG. 2. Seedling Type C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z

1.1.1. Seedling Type A

1.1.2. Seedling Type B

1.1.3. Seedling Type C

1.1.4. Seedling Type D

1.1.5. Seedling Type E

1.1.6. Seedling Type F

1.1.7. Seedling Type G

1.1.8. Seedling Type H

1.1.9. Seedling Type I

1.1.10. Seedling Type J

1.1.11. Seedling Type K

1.1.12. Seedling Type L

1.1.13. Seedling Type M

1.1.14. Seedling Type N

1.1.15. Seedling Type O

1.1.16. Seedling Type P

1.1.17. Seedling Type Q

1.1.18. Seedling Type R

1.1.19. Seedling Type S

1.1.20. Seedling Type T

1.1.21. Seedling Type U

1.1.22. Seedling Type V

1.1.23. Seedling Type W

1.1.24. Seedling Type X

1.1.25. Seedling Type Y

1.1.26. Seedling Type Z

1.1.27. Seedling Type A

1.1.28. Seedling Type B

1.1.29. Seedling Type C

1.1.30. Seedling Type D

1.1.31. Seedling Type E

1.1.32. Seedling Type F

1.1.33. Seedling Type G

1.1.34. Seedling Type H

1.1.35. Seedling Type I

1.1.36. Seedling Type J

1.1.37. Seedling Type K

1.1.38. Seedling Type L

1.1.39. Seedling Type M

1.1.40. Seedling Type N

1.1.41. Seedling Type O

1.1.42. Seedling Type P

1.1.43. Seedling Type Q

1.1.44. Seedling Type R

1.1.45. Seedling Type S

1.1.46. Seedling Type T

1.1.47. Seedling Type U

1.1.48. Seedling Type V

1.1.49. Seedling Type W

1.1.50. Seedling Type X

1.1.51. Seedling Type Y

1.1.52. Seedling Type Z



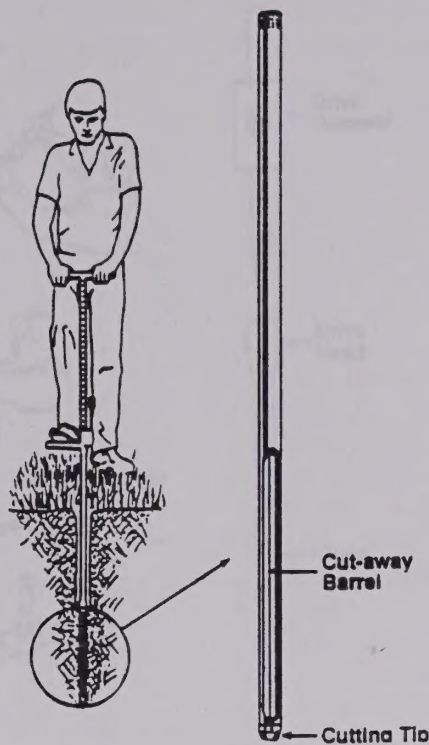


FIG. 6 Soil Sampling Tube

sampling tube is attached to extension rods to attain the target sampling depth. A cross-handle is attached to the uppermost rod. Extension rods are made of lightweight, durable metal. They are available in a variety of lengths depending on the manufacturer. Markings on the extensions and the sampler facilitate determining sample depths.

**7.5.4.2 Sampling Method**—The sampler is pushed into the ground by leaning on the unit's handle. Once the sampler has reached the bottom of the sampling interval, it is twisted to break soil continuity at the tip. Depending on the type of cutting edge, the tube sampler may obtain samples varying in diameter from 0.69 to 0.75 in. (1.75 to 1.91 cm).

**7.5.4.3 Comments**—The soil sampling tube works best in soft, clayey, cohesive soils. If the soil contains cobbles or rock fragments larger than about one-half the cutting tip diameter, satisfactory sampling may not be possible. If the soil is cohesionless, it will not be retained in the tube. With time, the cutting tip will be damaged and worn dull. Most units are designed so that this part can be replaced.

#### 7.5.5 Veihmeyer Tubes:

**7.5.5.1 Description**—The Veihmeyer tube is a long, complete cylinder. As shown in Fig. 6, this unit consists of a bevelled tip, that is threaded into the lower end of the tube, and a drive head threaded onto the upper end of the tube. The sampler is constructed of hardened steel. The tube is generally marked in even increments (for example, 1 ft or 0.30 m). These samplers are available in 4 to 16-ft (1.22 to 4.88-m) lengths with a 0.75-in. (1.91-cm) inside diameter.

**7.5.5.2 Sampling Method**—The lower guide rod of the drop hammer is slipped into the upper tube, through the

drive head (see Fig. 7). The hammer is used to pound the sampler into the ground. The sampler is then retrieved by pulling or jerking up on the hammer to force the sampler out of the soil cavity. Samples are extruded by forcing a rod through the tube.

**7.5.5.3 Comments**—Prior to sampling, the inside of the tube is sometimes coated with a lubricant to facilitate extrusion. However, the types of analyses to be performed on the samples should be considered to determine if the presence of lubricant will cause interference. Because the Veihmeyer sampler is a solid-walled tube and is fitted with a drop hammer, it can generally be used in more resistant soils than the soil sampling tube.

#### 7.5.6 Thin-Walled Tube Samplers:

**7.5.6.1 Description**—Thin-walled tube (Shelby Tube) samplers are readily available with 2, 3, and 5-in. (5.08, 7.62, and 12.70-cm) outside diameters and are commonly 30 in. (76.20 cm) long. The 3 by 30-in. (7.62 by 76.20-cm) outside diameter long sampler is most common. The advancing end of the sampler is rolled inwardly and has a cutting edge with a smaller diameter than the tube inside diameter. The cutting edge inside diameter reduction, defined as a "clearance ratio," is usually in the range of 0.0050 to 0.0150 or 0.50 to 1.50 % (Refer to Practice D 1587). The sampler tube is usually connected with set screws to a sampler head that in turn is threaded to connect with extension rods. Plastic and PTFE sealing caps for use after sampling are readily available for the 2, 3, and 5-in. (5.08, 7.62, and 12.70-cm) diameter tubes (refer to Practice D 4220). Shelby tubes are commonly available in carbon steel but can be manufactured from other metal (see Fig. 8).





Fig. 1. The Center of Gravity

...the head (see Fig. 1). The center of gravity is then located by ... the center of gravity is then located by ... the center of gravity is then located by ...

7.1.1.1. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

7.1.1.2. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

...the center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

7.1.1.3. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

7.1.1.4. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

7.1.1.5. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

7.1.1.6. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...

7.1.1.7. *Commentary*—The center of gravity is the point at which ... the center of gravity is the point at which ... the center of gravity is the point at which ...



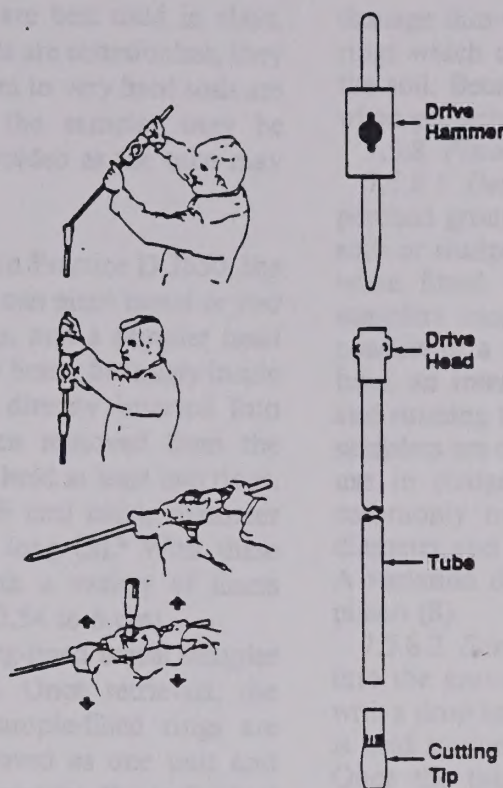


FIG. 7 Veilmeyer Tube

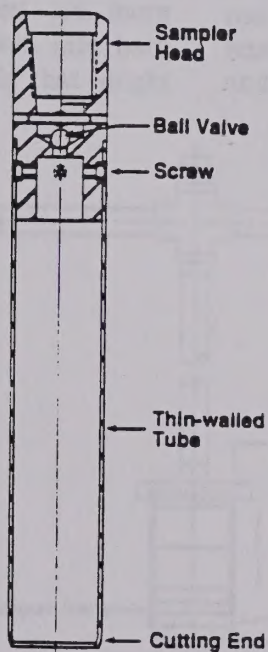


FIG. 8 Thin-Walled Tube Sampler

**7.5.6.2 Sampling Method**—The Shelby tube is pushed into soil by hand, with a jack-like system or with a hydraulic piston. The sample recovered is often less than the distance pushed, that is, the recovery ratio is less than 1.0. The recovery ratio is less than 1.0 because of soil compaction during sampling, and because friction between soil and the inner tube walls becomes greater than the shear strength of the soil in front of the tube. Consequently, soil in front of the

advancing end of the tube is displaced laterally rather than entering the tube (11). In general, shorter tubes provide less-disturbed samples than longer tubes. Samples are extruded from the Shelby tube with a hydraulic ram. As with all sampling devices, the most disturbed portion of the sample in contact with the tube is considered unrepresentative. Wilson et al. (12) developed a paring device to remove this outer layer of the core during extrusion.







**7.5.6.3 Comments**—Shelby tubes are best used in clays, silts, and fine-grained sands. If the soils are cohesionless, they may not be retained in the tube. If firm to very hard soils are encountered, driving (hammering) the sampler may be required. However, this should be avoided as the tube may buckle under the drive stress.

#### 7.5.7 Ring-Lined Barrel Samplers:

**7.5.7.1 Description**—As described in Practice D 3550, the ring-lined barrel sampler consists of a one piece barrel or two split barrel halves, a drive shoe, rings, and a sampler head (see Fig. 9). The rings, that are usually brass, fit snugly inside the barrel and are designed to be directly inserted into geotechnical testing apparatuses when removed from the barrel. Most samplers are designed to hold at least two rings. The barrel is commonly 3.5 in. (8.89 cm) inside diameter and 3.94 to 5.91 in. (10 to 15 cm) long (5).<sup>6</sup> With these lengths, the barrel can be fitted with a variety of liners ranging in length from 1 to 2.36 in. (2.54 to 6 cm).

**7.5.7.2 Sampling Method**—The ring-lined barrel sampler can be driven or pushed into soil. Once retrieved, the sampler is disassembled, and the sample-filled rings are removed. The rings are usually removed as one unit and placed into a capped container. Alternately, the individual soil-filled rings can be capped with plastic or PTFE and then sealed with wax or adhesive tape (refer to Practice D 4220).

**7.5.7.3 Comments**—Because barrel samplers are more rigid than thin-walled tubes, they can be driven into hard soils and soils containing sands and gravels that might

damage thin-walled tubes. The sampler provides samples in rings which can be handled without further disturbance of the soil. Because of this, these devices are most often used when geotechnical or chemical analyses are to be performed.

#### 7.5.8 Piston Samplers:

**7.5.8.1 Description**—Locally saturated (for example, by perched ground water), or cohesionless soils, and very soft soils or sludges may not be retained in most samplers, even when fitted with retainer baskets or flap valves. Piston samplers can be used in these situations. The sampler consists of a sampling tube, extension pipe attached to the tube, an internal piston, and rods connected to the piston and running through the extension pipe (see Fig. 10). These samplers are often built, as needed, out of common PVC (for use in sludge) or steel pipe fittings. The sampling tube commonly has a 0.75 to 3-in. (1.91 to 7.62-cm) inside diameter and is 8 in. to 9 ft (20.32 cm to 2.74 m) long (13). A variation designed for sampling peat has a cone shaped piston (8).

**7.5.8.2 Sampling Method**—The sampler can be pushed into the ground with the handle or driven into the ground with a drop hammer (13). As the tube is advanced, the piston is held stationary or pulled upward with the attached rods. Once the tube has been advanced through the sampling interval, it is rotated to break suction that might have developed between the soil and the outside wall of the tube. The sampler is then pulled to the surface keeping the piston rod fixed with respect to the extension pipe. The sample is retained because of suction that develops between the piston and the sample. Upon retrieval, the sample is extruded by

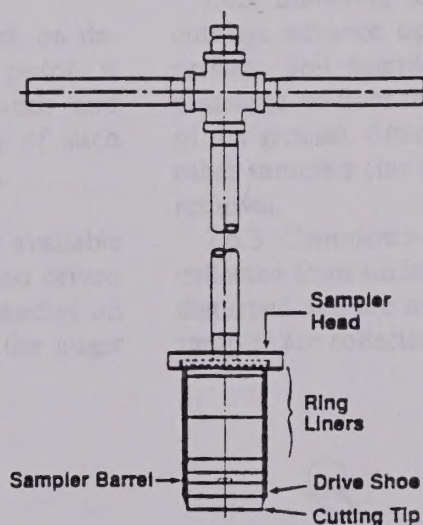


FIG. 9 Hand Operated Ring-Lined Barrel Sampler







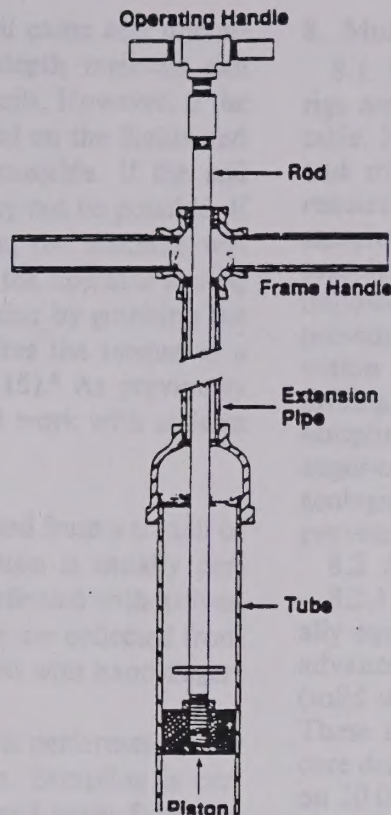


FIG. 10 Hand Operated Piston Sampler

using the piston to force the sample out of the tube. Sharma and De Dalta (14) described a cylindrical sampler for use in puddled soils that would flow back out of most samplers. The design includes a basal shutter that retains the sample while the sampler is withdrawn from the soil.

**7.5.8.3 Comments**—Because the sampler depends on development of suction between the sample and the piston, it may not work in unsaturated, coarse-grained sands and gravels. This is due to the high air permeability of such material that prevents the creation of high suction.

#### 7.6 Hand Held Power Augers:

**7.6.1 Description**—A very simple, commercially available auger consists of a solid flight auger attached to and driven by a small air-cooled engine (see Fig. 11). Two handles on the head assembly allow two operators to guide the auger

into the soil. Throttle and clutch controls are integrated into grips on the handles. Augers are available with diameters ranging from 2 to 16 in. (5.08 to 40.64 cm). The auger sections are commonly 3 ft (0.91 m) long.

**7.6.2 Sampling Method**—As the auger rotates into soil, cuttings advance up the flights and are discharged at the surface. Soil samples can be collected from the surface discharge, or from the auger flights after pulling the auger out of the ground. Alternatively, samples can be collected with other samplers (for example, a thin-walled tube) after auger removal.

**7.6.3 Comments**—As discussed in 7.3, if samples are collected from surface discharge or from the flights, they are disturbed and are not suitable for some uses. In addition, if samples are collected from surface discharge, it is difficult to

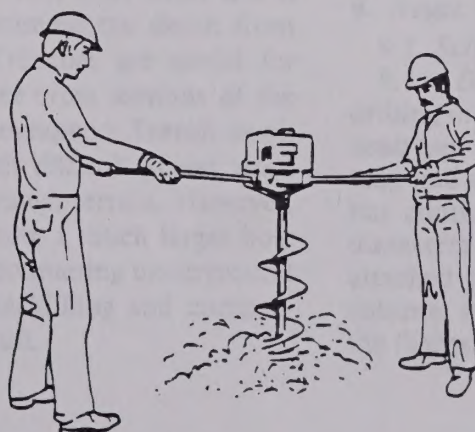


FIG. 11 Hand Held Power Auger







determine the depth from which the soil came and uncontrolled mixing of soil from different depth intervals can occur. The auger operates well in most soils. However, if the soil is cohesionless, it may not be retained on the flights and sampling in that fashion may not be possible. If the soil contains cobbles or boulders, drilling may not be possible. If the auger "hangs up" on an obstruction, the machine will start to rotate at the surface. Otherwise, the operator should not attempt to stop rotation of the machine by grabbing the handles. An alternate design that transfers the torque to a separate engine prevents this problem (15).<sup>6</sup> As previously stated, it is prudent to perform the field work with at least two people present.

#### 7.7 Trench Sampling:

**7.7.1 Description**—Soils may be sampled from a trench or pit excavated for that purpose. Excavation is usually performed by a backhoe, and samples are collected with knives, trowels, or shovels. Occasionally, samples are collected from the sides or the bottom of the trench or pit with hand augers or tube-type samplers.

**7.7.2 Sampling Method**—Excavation is performed under the guidance of the sampling technician. Sampling is performed only after the backhoe has moved away from the trench or pit. When the trench or pit is in unstable material or is more than a few feet deep, the sampling technician should only enter the trench or pit after it has been shored up or the sidewalls have been cut back to within the angle of repose (see Occupational Safety and Health Administration regulations). Otherwise, samples are more commonly collected at the surface from the bucket of the backhoe as excavation occurs.

**7.7.3 Comments**—The maximum sampling depth for the trench or pit method is dictated by the reach of the backhoe, the soil type and the moisture content of the soil. Maximum depths of up to 20 ft (6.10 m) can be obtained in moist clays. Maximum depths of less than 10 ft (3.05 m) are common in dry sands. Samples collected from the backhoe bucket should be taken from the center of the material to prevent collecting soil contaminated by the bucket surface, and to prevent inclusion of materials that may have fallen from above the desired sampling interval. However, when this is done, it is difficult to accurately estimate the depth from which the sample was obtained. Trenches are useful for obtaining lithologic information since cross sections of the vadose zone can be studied and photographed. Trench or pit sampling is often used in areas with difficult access since backhoes are designed to travel on rough terrain. However, because the process involves excavating a much larger hole than drilling methods, chances of encountering underground utilities are increased, and proper backfilling and compaction of the trench is often very difficult.

## 8. Multipurpose and Auger Drill Rigs

**8.1 Vadose zone samplers** used in conjunction with drill rigs are identical to those used to sample below the water table. However, commonly used drill rigs such as cable tool and rotary units are not recommended as they generally require the introduction of drilling fluids to the soils to be sampled. Air rotary drilling is also undesirable for obtaining samples for pore liquid or gas extraction. In most cases, hollow-stem augers with some type of cylindrical sampler provide the greatest level of assurance that soil sampled within the vadose zone was not carried downward by the drilling or sampling process. For some situations, such as sampling firm to very hard ground, using multipurpose auger-core-rotary drill rigs will be necessary. For some geologic circumstances the use of solid stem augers will provide an adequate drilling method.

#### 8.2 Multipurpose Auger-Core-Rotary Drill Rigs:

**8.2.1 Multipurpose auger-core-rotary drill rigs** are generally equipped with rotary power and vertical feed control to advance both hollow-stem augers and continuous flight (solid stem) augers to depths greater than 100 ft (30.48 m). These same drills have secondary capability for rotary and core drilling. The larger of these drills are typically mounted on 20 000 to 30 000-lb (9070 to 13605-kg) GVW trucks. The same multipurpose drill rigs are available on both rubber-tired and track-driven all-terrain carriers. The smaller of the multipurpose drills are typically mounted on trailers or one-ton, 4 by 4 trucks.

**8.2.2** When equipped with augers, the sampling process is identical to that for auger drill rigs. When multipurpose auger-core-rotary drill rigs or auger drill rigs are used, the speed of drilling and sampling is much greater than with hand operated equipment. Therefore it is useful to have a larger crew to efficiently handle, log, identify, and preserve the samples.

**8.3 Auger Drill Rigs**—Auger drill rigs are similar to multipurpose auger-core-rotary drill rigs. They are manufactured specifically for efficient auger drilling but do not have the pumps and hoists that are required for efficient core or rotary drilling. The rigs can be equipped with either solid stem or hollow stem augers. There are relatively few auger drills available in comparison to multipurpose auger-core-rotary drills.

## 9. Auger Drilling and Sampling

#### 9.1 Solid Stem Auger Drilling and Sampling:

**9.1.1 Description**—The tools used for solid-stem auger drilling include: auger sections, the drive cap, and the cutter head (see Fig. 12). Auger sections are typically 5 ft (1.52 m) long and are interchangeable for assembly in an articulated but continuously flighted column. Augers are available in diameters up to 24 in. (60.96 cm). The cutter head is attached to the lowermost or leading flight of the auger column. It is about 0.5 in. (1.25 cm) larger in diameter than the flights. Head types include fish tail or drag bits for use in







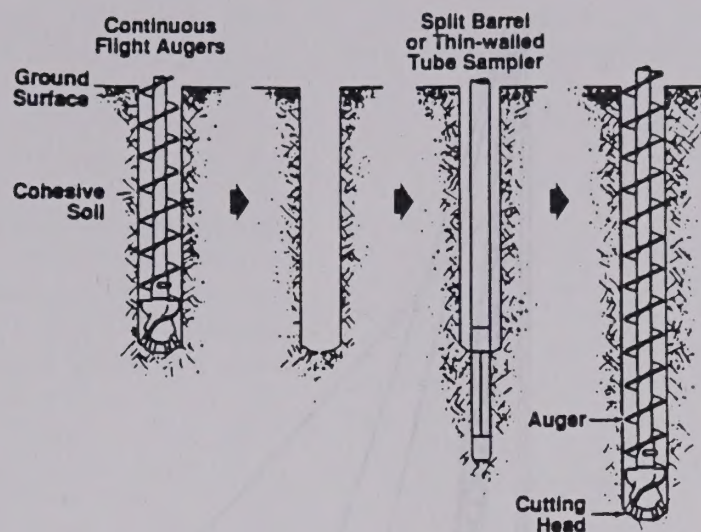


FIG. 12 - Solid Stem Auger Sampling

cohesionless materials, and clay or stinger bits for use in more consolidated material (16).

**9.1.2 Sampling Method**—As the auger column is rotated into soil, cuttings are retained on the flights. The augers are then removed from the hole and samples are taken from the retained soil. Samples obtained with solid stem augers are disturbed and are not core samples. Therefore, the samples are not suitable for analyses requiring undisturbed samples, such as hydraulic conductivity tests. This sampling method can provide an adequately clean borehole in some clayey and silty soils. However, when using the method in caving or squeezing ground, the quality and the origin of the recovered samples are questionable because soils from different intervals may have mixed. Therefore, when representative samples from discrete depths are desired, the borehole should be made large enough to insert a smaller diameter auger or another sampler (for example, a thin-walled tube) to the bottom of the borehole, without touching the sides of the borehole (see Fig. 11), to collect a discrete sample from the interval ahead.

**9.1.3 Comments**—Typical drilling depths with solid stem augers range from 50 to 120 ft (15.24 to 36.58 m). The greater drilling depths are attained in firm, silty and clayey soils. However, the depth to which the hole will remain open for sampling once the auger column has been removed is usually less than the maximum drilling depth. If cascading water or cohesionless soils are encountered, it can be expected that the hole will cave at that depth. The sample depth measurement, as taken from its location on an auger, is not precise. This is because soil may move up the flights in an uneven fashion as the auger column is advanced. As with hollow-stem augers, solid stem augers are often painted by the driller or manufacturer. It is prudent to remove this paint before drilling. The majority of the paint can be removed by drilling through sandy soils or by sand blasting. As with all

sampling devices, decontamination (for example, steam cleaning) should be performed between holes when chemical analyses are to be performed on the samples. This is especially important with the solid stem auger as it doubles as the drilling and sampling tool.

#### 9.2 Bucket Auger Drilling and Sampling:

**9.2.1 Description**—The bucket auger is a large diameter cylindrical bucket with auger-type cutting blades on the bottom. The bucket can have a diameter ranging from 12 in. (30.48 cm) up to 6 ft (1.83 m) with lengths varying from 24 to 48 in. (60.96 to 121.92 cm) (17). The bottom is hinged to allow cuttings to be emptied out (see Fig. 13).

**9.2.2 Sampling Method**—The bucket is rotated to depth in the vadose zone until the bucket is full. Therefore, depending on the bucket length, sampling intervals can range from 24 to 48 in. (60.96 to 121.92 cm). Sampling consists of extracting small diameter core samples from the interior of the bucket after lowering the full bucket to the ground (see Section 7). This approach minimizes problems with undisturbed mixing of discrete portions to be sampled.

**9.2.3 Comments**—The bucket auger is best suited for sampling from relatively stable clays as the caving problems discussed in 9.1.3 are amplified by the larger hole diameter. Boulders can impede drilling and may have to be individually removed from the hole before sampling can continue (15)<sup>6</sup>. Generally, boulders up to one-third or one-fourth the bucket diameter can be picked up by the bucket. Common sampling depths are less than 50 ft (15.24 m) but holes up to 250 ft (76.20 m) deep have been drilled (16, 17).

#### 9.3 Hollow Stem Auger Drilling and Sampling:

**9.3.1 Description**—Outer components of the hollow stem auger system include: hollow auger sections, the hollow auger head, and the drive cap. Inner components include: the pilot assembly, the center rod column, and the rod-to-cap adaptor (see Fig. 14). The auger head contains replaceable carbide teeth that pulverize the formation during flight







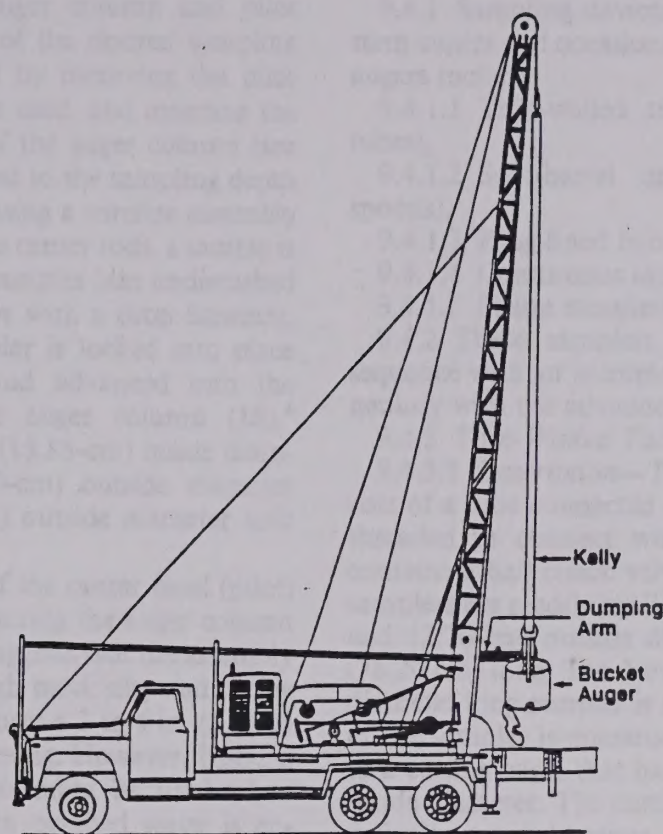


FIG. 13 Bucket Auger and Drilling Rig

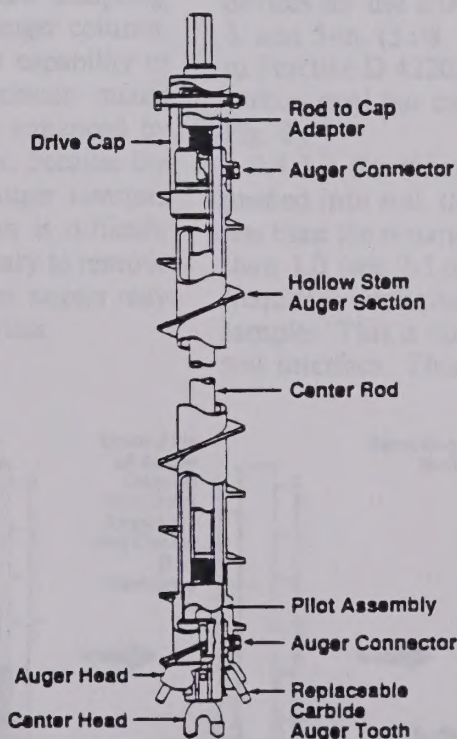


FIG. 14 Hollow-Stem Auger Components

column rotation. The cutting diameter is somewhat greater than the flighting diameter because of the protruding teeth. Auger sections are typically 5 ft (1.52 m) long and are interchangeable for assembly in an articulated but continuously flighted column. Drilling progresses in 5 ft (1.52 m) or shorter increments and sampling can be accomplished at any

depth within that increment. Upon advancement of a 5 ft (1.52 m) increment, another 5 ft (1.52 m) section of hollow-stem auger and center rod is added. Hollow-stem augers are readily available with 2.25, 2.75, 3.25, 3.75, 4.25, 6.25, and 8.25-in. (5.72, 6.99, 8.26, 9.53, 10.80, 15.88, and 20.96-cm) inside diameters.







**9.3.2 Sampling Method**—The auger column and pilot assembly are advanced to the top of the desired sampling interval. Sampling is accomplished by removing the pilot assembly and center rod, if they are used, and inserting the sampler through the hollow stem of the auger column (see Fig. 15). The sampler may be lowered to the sampling depth by attaching it to center rods or by using a wireline assembly (12). When the sampler is attached to center rods, a sample is collected by pushing or driving the sampler into undisturbed soil with the rig hydraulic system or with a drop hammer. When a wireline is used, the sampler is locked into place ahead of the lower-most auger and advanced into the sampling interval by rotating the auger column (18).<sup>6</sup> Hollow stem augers with a 6.25-in. (15.88-cm) inside diameter allow the use of 5-in. (12.70-cm) outside diameter Shelby tubes and 4.5-in. (11.43-cm) outside diameter split barrel samplers (see 9.4).

**9.3.3 Comments**—The purpose of the center head (pilot) assembly is to prevent soils from entering the auger column as it is advanced (19). Driscoll (17) suggests that the assembly may be omitted when drilling through hard, silty and clayey soils as these materials will usually form a 2 to 4 in. (5.08 to 10.16 cm) long plug at the auger opening. However, Hackett (19) recommends that the pilot assembly be used when detailed samples are required. When perched water is encountered, “heaving sands” that move up into the auger column upon pilot assembly removal during sampling, may be a concern. Various one-way plugs that allow sampling, but that prevent sand from moving into the auger column, are described in Hackett (19). The important capability of being able to obtain samples that do not contain mixed material from shallow sources in the hole is enhanced by using the hollow-stem auger method. However, because the sections are hollow, decontamination of the auger interiors between holes to prevent cross contamination is difficult. High pressure steam cleaners are usually necessary to remove caked-on soils and contaminants. Hollow stem augers may advance rapidly through unconsolidated materials.

#### 9.4 Sampling Devices:

9.4.1 Sampling devices used in conjunction with hollow stem augers and occasionally in holes advanced by solid stem augers include:

9.4.1.1 Thin-walled tube samplers (also called Shelby tubes),

9.4.1.2 Split-barrel drive samplers (also called Split spoons),

9.4.1.3 Ring-lined barrel samplers,

9.4.1.4 Continuous sample tube systems, and

9.4.1.5 Piston samplers.

9.4.2 These samplers are either pushed or driven in sequence with an increment of drilling or advanced simultaneously with the advance of a hollow stem auger column.

#### 9.4.3 Thin-Walled Tube Samplers:

9.4.3.1 *Description*—The thin-walled tube sampler consists of a tube connected to a head with screws. The head is threaded to connect with standard drill rods. The head contains a ball check valve. Thin-walled tube (Shelby tube) samplers are readily available with 2, 3, and 5-in. (5.08, 7.62, and 12.70-cm) outside diameter and are commonly 30 in. (76.20 cm) long. The 3 by 30 in. (7.62 by 76.20 cm) outside diameter long sampler is most common. The advancing end of the sampler is constructed with an inward lip, machined to a cutting edge, that has a smaller diameter than the tube inside diameter. The cutting edge inside diameter reduction, defined as a “clearance ratio,” is usually in the range of 0.0050 to 0.0150 or 0.50 to 1.50 % (refer to Practice D 1587). PTFE or plastic sealing caps and other sealing devices for use after sampling are readily available for the 2, 3, and 5-in. (5.08, 7.62 and 12.70-cm) diameter tubes (refer to Practice D 4220). Shelby tubes are commonly available in carbon steel but can be manufactured from other metal (see Fig. 8).

9.4.3.2 *Sampling Methods*—When a Shelby tube is pushed into soil, the length of the sample recovered is often less than the distance pushed, that is, the recovery ratio is less than 1.0 (see 7.5.6.2). In addition, a portion of the sample frequently remains in the borehole after retrieval of the sampler. This is due to suction that develops at the sampler-soil interface. This suction may be broken by twisting the

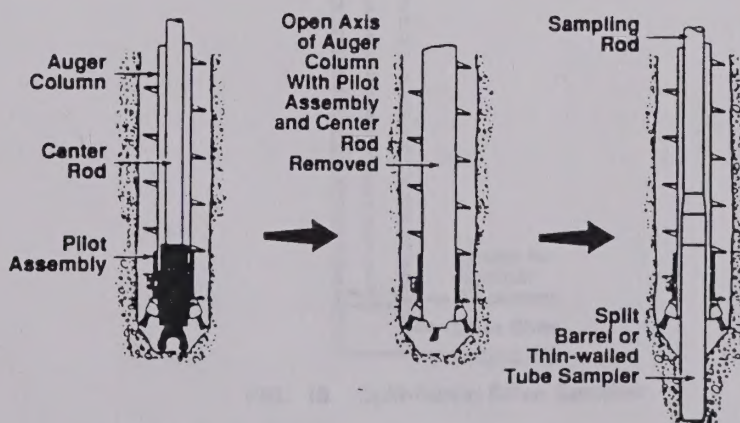


FIG. 15 Hollow-Stem Auger Sampling







sampler prior to retrieval or by advancing the auger column below the base of the sampler before retrieval (20). Samples are extruded from the Shelby tube with a hydraulic ram. As with all sampling devices, the portion of the sample in contact with the tube is considered disturbed and unrepresentative. Wilson et al. (12) developed a paring device to remove this outer layer of the core during extrusion.

**9.4.3.3 Comments**—The ball check valve was originally intended to provide a vent for drilling fluids when pushing the tube into soil, and also to prevent the column of fluid within the drill stem from forcing the sample out of the tube during retrieval. Since drilling fluids are not used when sampling in the vadose zone, these considerations are not important. However, the valve does provide a vent for air displaced as the sampler is pushed into soil. Shelby tubes are best used in clays, silts, and fine grained sands. They can be pushed with the hydraulic system of most drill rigs in fine grained sands that are loose to moderately consolidated or in clays and silts that are soft to firm. If the soils are cohesionless, they may not be retained in the tube. If consolidated or hard soils are encountered, driving the sampler may be required. However, some tubes may buckle under the drive stress. A spring-loaded barrel has been developed to protect the Shelby tube from buckling when sampling these soils (21).<sup>6</sup>

#### 9.4.4 Split-Barrel Drive Samplers:

**9.4.4.1 Description**—The split-barrel drive sampler consists of two split-barrel halves, a drive shoe, and a sampler head containing a ball check valve, all of which are threaded together (see Fig. 15). The most common size has a 2-in. (5.08-cm) outside diameter and a 1.5-in. (3.81-cm) inside diameter split barrel with a 1.375-in. (3.49-cm) inside diameter drive shoe. This sampler is used extensively in geotechnical exploration (Refer to Method D 1586). When fitted with a 16 gage liner for encased cores, the sampler has a 1.375-in. (3.49-cm) inside diameter throughout. A 3-in. (7.62-cm) outside diameter by 2.5-in. (6.35-cm) inside diameter split-barrel sampler with a 2.375-in. (6.03-cm) inside diameter drive shoe is also available (22).<sup>6</sup> Other split-barrel samplers in the size range of 2.5-in. (6.35-cm) to 4.5-in. (11.43-cm) outside diameter are manufactured but are less common. A plastic or metal retainer basket, or a flap valve is often fitted into the drive shoe to prevent samples from falling out during retrieval.

**9.4.4.2 Sampling Method**—As described in Method D 1586 the sampler is threaded onto drilling rods and is lowered to the bottom of the boring. The sampler is then driven into the soil with blows from a drop hammer attached to the drill rig. The hammer usually weighs 140 lb and is operated by the driller. The sampler is extracted from the soil in a manner that will ensure maximum sample recovery. A

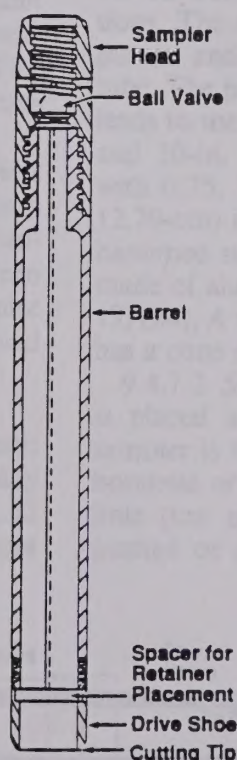


FIG. 16 Split-Barrel Drive Sampler







sample is obtained by disassembling the drive shoe and head, and splitting the barrel to expose the core of soil. Material disturbed by contact with the barrel can be scraped away, or a less disturbed interior portion collected with a spatula.

**9.4.4.3 Comments**—Split barrel drive samplers can be used in all soil types if the larger grain sizes can enter through the opening of the drive shoe. Because the sampler can be fitted with a retainer basket, it is typically used in place of thin-walled tubes when cohesionless soils are to be sampled.

#### 9.4.5 Ring-Lined Barrel Samplers:

**9.4.5.1 Description**—As described in Practice D 3550, the ring-lined barrel sampler consists of a one piece barrel or two split-barrel halves, a drive shoe, rings, a waste barrel and a sampler head containing a ball check valve (see Fig. 17). The rings fit snugly inside the barrel and are designed to be directly inserted into geotechnical testing apparatus when removed from the barrel. Most samplers are designed to hold at least six rings. The waste barrel provides a space above the rings into which disturbed soil, originally at the bottom of the hole, can move. The samplers are commonly available with 2, 3, and 4-in. (5.08, 7.62, and 10.16-cm) outside diameter.

**9.4.5.2 Sampling Method**—The ring-lined barrel sampler can be driven or pushed into soil. It is important to insert the sampler deep enough to allow all disturbed soil to move through the rings and into the waste barrel. Once retrieved, the sampler is disassembled, and the sample filled rings are carefully removed. The rings are usually removed as one unit and placed into a capped container. Alternately, the individual soil filled rings can be capped with plastic or PTFE and even sealed with wax or adhesive tape (refer to Practice D 4220).

**9.4.5.3 Comments**—Because ring-lined barrel samplers are more rigid than thin-walled tubes, they can be driven into soils containing sands and gravels that might damage thin-walled tubes. The sampler provides samples in rings that can be handled without further disturbance of the soil. Because of this, these devices are most often used when geotechnical or chemical analyses are to be performed.

#### 9.4.6 Continuous Sample Tube System:

**9.4.6.1 Description**—Continuous sample tube systems that fit within a hollow-stem auger column are readily available in North America. The barrel is typically 5 ft (1.52 m) long, and fits within the lead auger of the hollow auger

column. The sampler is prevented from rotating as the auger column is turned (20). For many conditions the sampler provides continuous, 5-ft (1.52-m) samples (see Fig. 18). The assembly can be split- or solid-barrel and can be used with or without liners of various metallic and nonmetallic materials (20). Two clear, plastic, 30 in. (76.20 cm) long liners are often used. The sampler may also be fitted with a plastic or metal retainer basket, or a flap valve to prevent cohesionless soils from falling out of the sampler during retrieval (20).

**9.4.6.2 Sampling Method**—The sampler is locked in place inside the auger column with its open end protruding a short distance beyond the end of the column. While advancing the column, soil enters the non-rotating sampling barrel. After a 5-ft (1.52-m) advance, the sampler is withdrawn, and the liner (if used) is removed and capped.

**9.4.6.3 Comments**—The continuous sample tube system replaces the pilot head assembly in the hollow-stem auger column. Because of this, sampling speed is greatly increased since the pilot assembly does not have to be removed before taking a sample. The continuous sample tube system is best used in clays, silts, and in fine grained sands. It can be used to sample soils that are much more consolidated or harder than can be sampled with Shelby tubes.

#### 9.4.7 Piston Samplers:

**9.4.7.1 Description**—Locally saturated (for example, perched ground water), or cohesionless soils, and very soft soils or sludges may not be retained in most samplers, even when they have been fitted with retainer baskets or flap valves. Piston samplers are often used under these conditions. The sampler consists of a sampling tube, an internal piston, and a drive head. The piston fits snugly inside the tube. The piston is attached to a rod assembly or a cable that leads to the surface. Tubes made of steel are available in 5.5 and 30-in. (13.97 and 76.20-cm) and 5-ft (1.5-m) lengths with 0.75, 2, 3, 4, and 5-in. (1.91, 5.08, 7.62, 10.16, and 12.70-cm) inside diameter (22, 23). When equipped with a hardened steel drive shoe, the tube can be fitted with a liner made of aluminum clear PVC, or another material (see Fig. 19) (24). A version of the sampler designed for peat sampling has a cone shaped piston (8).

**9.4.7.2 Sampling Method**—Prior to sampling, the piston is placed at the base (advancing end) of the tube. The sampler is then attached to drill rods and lowered down the borehole or hollow-stem auger column to the bottom of the hole (top of the sampling interval). The sampler is then pushed or driven into the sampling interval. As the tube

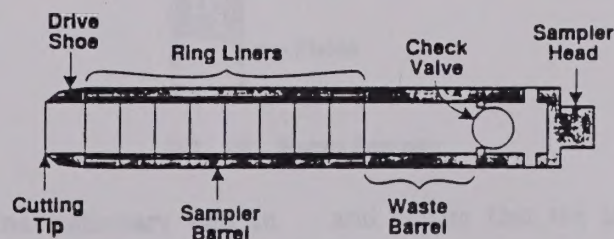


FIG. 17 Ring-Lined Barrel Sampler







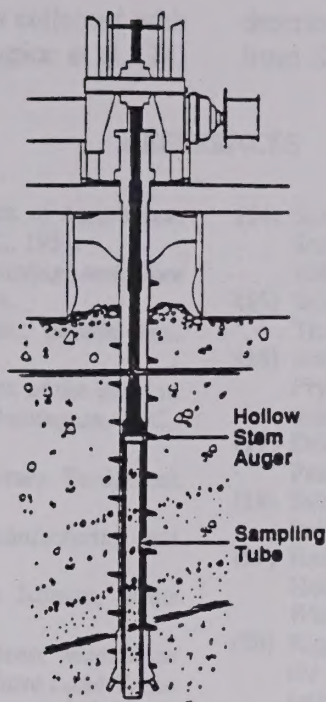


FIG. 18 Continuous Sample Tube System

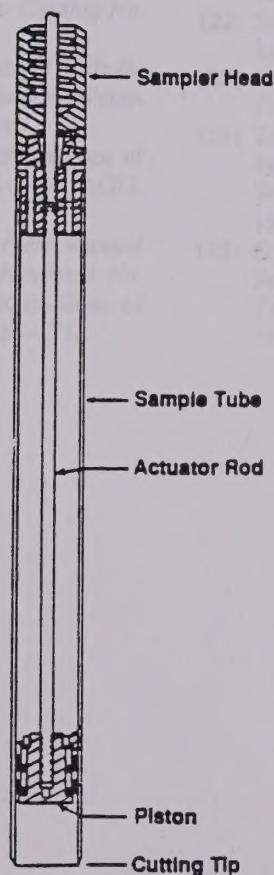


FIG. 19 Piston Sampler

moves downward, the piston remains stationary and in contact with the top of the soil sample. When the sampler is withdrawn, soil is retained because of suction that develops between the piston and the soil core within the sampler. This suction is stronger than the suction at the bottom of the sampler that would tend to extract soil from the sampler. Even so, it is often useful to twist the sampler with the drill rods prior to retrieval, to break suction at the bottom end

and ensure that the sample will not be pulled out of the sampler.

**9.4.7.3 Comments**—Average recovery ratios greater than 0.9 can be attained with this sampling tool (24, 25). However, because the sampler depends on development of suction between the sample and the piston, it may not work in unsaturated, coarse grained sands and gravels. This is due to the high air permeability of such material that prevents the







creation of suction with the sampler. Samples collected with piston samplers are relatively undisturbed. Zapico et al. (24)

described techniques for extracting fluid samples directly from liners, and for converting liners into permeameters.

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The following is a list of the names of the persons who have been appointed to the various committees of the Board of Directors of the City of New York, for the year 1911.

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# Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)<sup>1</sup>

This standard is issued under the fixed designation D 4750; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method describes the procedures for measuring the level of liquid in a borehole or well and determining the stabilized level of liquid in a borehole.

1.2 The test method applies to boreholes (cased or uncased) and monitoring wells (observation wells) that are vertical or sufficiently vertical so a flexible measuring device can be lowered into the hole.

1.3 Borehole liquid-level measurements obtained using this test method will not necessarily correspond to the level of the liquid in the vicinity of the borehole unless sufficient time has been allowed for the level to reach equilibrium position.

1.4 This test method generally is not applicable for the determination of pore-pressure changes due to changes in stress conditions of the earth material.

1.5 This test method is not applicable for the concurrent determination of multiple liquid levels in a borehole.

1.6 The values stated in inch-pound units are to be regarded as the standard.

1.7 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Document

### 2.1 ASTM Standard:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>

## 3. Terminology

### 3.1 Descriptions of Terms Specific to This Standard:

3.1.1 **borehole**—a hole of circular cross-section made in soil or rock to ascertain the nature of the subsurface materials. Normally, a borehole is advanced using an auger, a drill, or casing with or without drilling fluid.

3.1.2 **earth material**—soil, bedrock, or fill.

3.1.3 **ground-water level**—the level of the water table surrounding a borehole or well. The ground-water level can be represented as an elevation or as a depth below the ground surface.

3.1.4 **liquid level**—the level of liquid in a borehole or well at a particular time. The liquid level can be reported as an elevation or as a depth below the top of the land surface. If the liquid is ground water it is known as water level.

3.1.5 **monitoring well (observation well)**—a special well drilled in a selected location for observing parameters such as liquid level or pressure changes or for collecting liquid samples. The well may be cased or uncased, but if cased the casing should have openings to allow flow of borehole liquid into or out of the casing.

3.1.6 **stabilized borehole liquid level**—the borehole liquid level which remains essentially constant with time, that is, liquid does not flow into or out of the borehole.

3.1.7 **top of borehole**—the surface of the ground surrounding the borehole.

3.1.8 **water table (ground-water table)**—the surface of a ground-water body at which the water pressure equals atmospheric pressure. Earth material below the ground-water table is saturated with water.

### 3.2 Definitions:

3.2.1 For definitions of other terms used in this test method, see Terminology D 653.

## 4. Significance and Use

4.1 In geotechnical, hydrologic, and waste-management investigations, it is frequently desirable, or required, to obtain information concerning the presence of ground water or other liquids and the depths to the ground-water table or other liquid surface. Such investigations typically include drilling of exploratory boreholes, performing aquifer tests, and possibly completion as a monitoring or observation well. The opportunity exists to record the level of liquid in such boreholes or wells, as the boreholes are being advanced and after their completion.

4.2 Conceptually, a stabilized borehole liquid level reflects the pressure of ground water or other liquid in the earth material exposed along the sides of the borehole or well. Under suitable conditions, the borehole liquid level and the ground-water, or other liquid, level will be the same, and the former can be used to determine the latter. However, when earth materials are not exposed to a borehole, such as material which is sealed off with casing or drilling mud, the borehole water levels may not accurately reflect the ground-water level. Consequently, the user is cautioned that the liquid level in a borehole does not necessarily bear a relationship to the ground-water level at the site.

4.3 The user is cautioned that there are many factors which can influence borehole liquid levels and the interpretation of borehole liquid-level measurements. These factors are not described or discussed in this test method. The

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

Current edition approved Nov. 27, 1987. Published January 1988.

<sup>2</sup> Annual Book of ASTM Standards, Vol 04.08.







interpretation and application of borehole liquid-level information should be done by a trained specialist.

4.4 Installation of piezometers should be considered where complex ground-water conditions prevail or where changes in intergranular stress, other than those associated with fluctuation in water level, have occurred or are anticipated.

## 5. Apparatus

5.1 Apparatus conforming to one of the following shall be used for measuring borehole liquid levels:

5.1.1 *Weighted Measuring Tape*—A measuring tape with a weight attached to the end. The tape shall have graduations that can be read to the nearest 0.01 ft. The tape shall not stretch more than 0.05 % under normal use. Steel surveying tapes in lengths of 50, 100, 200, 300, and 500 ft (20, 30, 50 or 100 m) and widths of ¼ in. (6 mm) are commonly used. A black metal tape is better than a chromium-plated tape. Tapes are mounted on hand-cranked reels up to 500 ft (100 m) lengths. Mount a slender weight, made of lead, to the end of the tape to ensure plumbness and to permit some feel for obstructions. Attach the weight to the tape with wire strong enough to hold the weight but not as strong as the tape. This permits saving the tape in the event the weight becomes lodged in the well or borehole. The size of the weight shall be such that its displacement of water causes less than a 0.05-ft (15-mm) rise in the borehole water level, or a correction shall be made for the displacement. If the weight extends beyond the end of the tape, a length correction will be needed in measurement Procedure C (see 7.2.3).

5.1.2 *Electrical Measuring Device*—A cable or tape with electrical wire encased, equipped with a weighted sensing tip on one end and an electric meter at the other end. An electric circuit is completed when the tip contacts water; this is registered on the meter. The cable may be marked with graduations similar to a measuring tape (as described in 5.1.1).

5.1.3 *Other Measuring Devices*—A number of other recording and non-recording devices may be used. See Ref. (1) for more details.<sup>3</sup>

## 6. Calibration and Standardization

6.1 Calibrate measuring apparatus in accordance with the manufacturers' directions.

## 7. Procedure

7.1 Liquid-level measurements are made relative to a reference point. Establish and identify a reference point at or near the top of the borehole or a well casing. Determine and record the distance from the reference point to the top of the borehole (land surface). If the borehole liquid level is to be reported as an elevation, determine the elevation of the reference point or the top of borehole (land surface). Three alternative measurement procedures (A, B, and C) are described.

NOTE 1—In general, Procedure A allows for greater accuracy than B or C, and B allows for greater accuracy than C; other procedures have a

variety of accuracies that must be determined from the referenced literature (2–5).

### 7.2 Procedure A—Measuring Tape:

7.2.1 Chalk the lower few feet of tape by drawing the tape across a piece of colored carpenter's chalk.

7.2.2 Lower a weighted measuring tape slowly into the borehole or well until the liquid surface is penetrated. Observe and record the reading on the tape at the reference point. Withdraw the tape from the borehole and observe the lower end of the tape. The demarcation between the wetted and unwetted portions of the chalked tape should be apparent. Observe and record the reading on the tape at that point. The difference between the two readings is the depth from the reference point to the liquid level.

NOTE 2—Submergence of the weight and tape may temporarily cause a liquid-level rise in wells or boreholes having very small diameters. This effect can be significant if the well is in materials of very low hydraulic conductivity.

NOTE 3—Under dry surface conditions, it may be desirable to pull the tape from the well or borehole by hand, being careful not to allow it to become kinked, and reading the liquid mark before rewinding the tape onto the reel. In this way, the liquid mark on the chalked part of the tape is rapidly brought to the surface before the wetted part of the tape dries. In cold regions, rapid withdrawal of the tape from the well is necessary before the wet part freezes and becomes difficult to read. The tape must be protected if rain is falling during measurements.

NOTE 4—In some pumped wells, or in contaminated wells, a layer of oil may float on the water. If the oil layer is only a foot or less thick, read the tape at the top of the oil mark and use this reading for the water-level measurement. The measurement will not be greatly in error because the level of the oil surface in this case will differ only slightly from the level of the water surface that would be measured if no oil was present. If several feet of oil are present in the well, or if it is necessary to know the thickness of the oil layer, a water-detector paste for detecting water in oil and gasoline storage tanks is available commercially. The paste is applied to the lower end of the tape that is submerged in the well. It will show the top of the oil as a wet line and the top of the water as a distinct color change.

7.2.3 As a standard of good practice, the observer should make two measurements. If two measurements of static liquid level made within a few minutes do not agree within about 0.01 or 0.02 ft (generally regarded as the practical limit of precision) in boreholes or wells having a depth to liquid of less than a couple of hundred feet, continue to measure until the reason for the lack of agreement is determined or until the results are shown to be reliable. Where water is dripping into the hole or covering its wall, it may be impossible to get a good water mark on the chalked tape.

7.2.4 After each well measurement, in areas where polluted liquids or ground water is suspected, decontaminate that part of the tape measure that was wetted to avoid contamination of other wells.

### 7.3 Procedure B—Electrical Measuring Device:

7.3.1 Check proper operation of the instrument by inserting the tip into water and noting if the contact between the tip and the water surface is registered clearly.

NOTE 5—In pumped wells having a layer of oil floating on the water, the electric tape will not respond to the oil surface and, thus, the liquid level determined will be different than would be determined by a steel tape. The difference depends on how much oil is floating on the water. A miniature float-driven switch can be put on a two-conductor electric tape that permits detection of the surface of the uppermost fluid.

<sup>3</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.















SITE NO.

# BOREHOLE OR WELL SCHEDULE FORM

Recorded by \_\_\_\_\_

Date \_\_\_\_\_

Check One \_\_\_\_\_ English \_\_\_\_\_ Metric Units

## GENERAL SITE DATA (1)

Site Ident No  RG Number  Transaction

Site-Type  Data  Reliability  Reporting Agency

Project No  District  State  Country

Latitude  Longitude  Lat-Long Accuracy

Local Number  Land No  Loc

Location Map  Scale

Altitude  Method of Measurement  Accuracy

Topo Setting  Hydrologic Unit (OWDC)

Use of Site  Secondary Site Use  Tertiary Site Use

Use of Water

Secondary Water Use  Tertiary Use of Water  Depth of Hole  Depth of Well  Source of Depth Data

Water Level  Data Measured  Source

Method of Measurement

Site Status

Source of Geohydrologic Data  Pump Used  Date of First Construction

## OWNER IDENTIFICATION (1)

R-158  T- A D M  Date of Ownership

Name: Last  First  Middle Initial

## OTHER SITE IDENTIFICATION NUMBERS (1)

R-189  T- A D M  Ident  Assigner

New Card Same R & T  Ident  Assigner

## SITE VISIT DATA (1)

R-186  T- A D M  Date of Visit  Name of Person

## FIELD WATER QUALITY MEASUREMENTS (1)

R-192  T- A D M  Date  Geohydrologic Unit

New Card Same R thru 195

Temperature  Degrees C

Conductance   $\mu$ Mhos

Other (STORE) Parameter  Value

Other (STORE) Parameter  Value

## FOOT NOTES

① Source of Data Codes

A	D	G	L	M	O	R	S	Z
Other	driller	water	log	memory	name	other	reporting	other
code								

FIG. 3 Example of a Borehole or Well Schedule Form







NOTE 8—The time required to reach equilibrium can be reduced by removing or adding liquid until the liquid level is close to the estimated stabilized level.

8.2 Use one of the following two procedures to determine the stabilized liquid level.

8.2.1 *Procedure 1*—Take a series of liquid-level measurements until the liquid level remains constant with time. As a minimum, two such constant readings are needed (more readings are preferred). The constant reading is the stabilized liquid level for the borehole or well.

NOTE 9—If desired, the time and level data could be plotted on graph paper in order to show when equilibrium is reached.

8.2.2 *Procedure 2*—Take at least three liquid-level measurements at approximately equal time intervals as the liquid level changes during the approach to a stabilized liquid level.

8.2.2.1 The approximate position of the stabilized liquid level in the well or borehole is calculated using the following equation:

$$h_o = \frac{y_1^2}{y_1 - y_2}$$

where:

$h_o$  = distance the liquid level must change to reach the stabilized liquid level,

$y_1$  = distance the liquid level changed during the time interval between the first two liquid-level readings, and

$y_2$  = distance the liquid level changed during the time interval between the second and the third liquid level readings.

8.2.2.2 Repeat the above process using successive sets of three measurements until the  $h_o$  computed is consistent to the accuracy desired. Compute the stabilized liquid level in the well or borehole.

NOTE 10—The time span required between readings for Procedures 1 and 2 depends on the permeability of the earth material. In material with comparatively high permeability (such as sand), a few minutes may be sufficient. In materials with comparatively low permeability (such as clay), many hours or days may be needed. The user is cautioned that in clayey soils the liquid in the borehole or well may never reach a stabilized level equivalent to the liquid level in the earth materials surrounding the borehole or well.

## 9. Report

9.1 For borehole or well liquid-level measurements, report, as a minimum, the following information:

9.1.1 Borehole or well identification.

9.1.2 Description of reference point.

9.1.3 Distance between reference point and top of borehole or land surface.

9.1.4 Elevation of top of borehole or reference point (if the borehole or well liquid level is reported as an elevation).

9.1.5 Description of measuring device used, and graduation.

9.1.6 Procedure of measurement.

9.1.7 Date and time of reading.

9.1.8 Borehole or well liquid level.

9.1.9 Description of liquid in borehole or well.

9.1.10 State whether borehole is cased, uncased, or contains a monitoring (observation) well standpipe and give description of, and length below top of borehole of, casing or standpipe.

9.1.11 Drilled depth of borehole, if known.

9.2 For determination of stabilized liquid level, report:

9.2.1 All pertinent data and computations.

9.2.2 Procedure of determination.

9.2.3 The stabilized liquid level.

9.3 *Report Forms*—An example of a borehole or well-schedule form is shown in Fig. 1. An example of a liquid-level measurement form, for recording continuing measurements for a borehole or well, is shown in Fig. 2. An example of a borehole or well schedule form designed to facilitate computer data storage is shown in Fig. 3.

## 10. Precision and Bias

10.1 Borehole liquid levels shall be measured and recorded to the accuracy desired and consistent with the accuracy of the measuring device and procedures used. Procedure A multiple measurements by wetted tape should agree within 0.02 ft (6 mm). Procedure B multiple measurements by electrical tape should agree within 0.04 ft (12 mm). Procedure C multiple measurements by tape and sounding weight should agree within 0.04 ft (12 mm). Garber and Koopman (2) describe corrections that can be made for effects of thermal expansion of tapes or cables and of stretch due to the suspended weight of tape or cable and plumb weight when measuring liquid levels at depths greater than 500 ft (150 m).

## REFERENCES

- (1) "National Handbook of Recommended Methods for Water Data Acquisition—Chapter 2—Ground Water", Office of Water Data Coordination, Washington, DC, 1980.
- (2) Garber, M. S., and Koopman, F. C., "Methods of Measuring Water Levels in Deep Wells," *U.S. Geologic Survey Techniques for Water Resources Investigations*, Book 8, Chapter A-1, 1968.
- (3) Hvorslev, M. J., "Ground Water Observations," in *Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes*, American Society Civil Engineers, New York, NY, 1949.
- (4) Zegarra, E. J., "Suggested Method for Measuring Water Level in Boreholes," *Special Procedures for Testing Soil and Rock for Engineering Purposes*, ASTM STP 479, ASTM, 1970.
- (5) "Determination of Water Level in a Borehole," CSA Standard A 119.6 - 1971, Canadian Standards Association, 1971.







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# Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers<sup>1</sup>

This standard is issued under the fixed designation D 5092; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## INTRODUCTION

This practice for the design and installation of ground water monitoring wells in aquifers will promote (1) durable and reliable construction, (2) extraction of representative ground water quality samples, and (3) efficient and site hydrogeological characterizations. The guidelines established herein are affected by governmental regulations and by site specific geological, hydrogeological, climatological, topographical, and subsurface chemistry conditions. To meet these geoenvironmental challenges, this guidance promotes the development of a conceptual hydrogeologic model prior to monitoring well design and installation.

## 1. Scope

1.1 This practice considers the selection and characterization (that is, defining soil, rock types, and hydraulic gradients) of the target monitoring zone as an integral component of monitoring well design and installation. Hence, the development of a conceptual hydrogeologic model for the intended monitoring zone(s) is recommended prior to the design and installation of a monitoring well.

1.2 These guidelines are based on recognized methods by which monitoring wells may be designed and installed for the purpose of detecting the presence or absence of a contaminant, and collecting representative ground water quality data. The design standards and installation procedures herein are applicable to both detection and assessment monitoring programs for facilities.

1.3 The recommended monitoring well design, as presented in this practice, is based on the assumption that the objective of the program is to obtain representative ground water information and water quality samples from aquifers. Monitoring wells constructed following this practice should produce relatively turbidity-free samples for granular aquifer materials ranging from gravels to silty sand and sufficiently permeable consolidated and fractured strata. Strata having grain sizes smaller than the recommended design for the smallest diameter filter pack materials should be monitored by alternative monitoring well designs which are not addressed in this practice.

1.4 The values stated in inch-pound units are to be regarded as standard. The values in parentheses are for information only.

1.5 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and*

*health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

C 150 Specification for Portland Cement<sup>2</sup>

C 294 Descriptive Nomenclature of Constituents of Natural Mineral Aggregates<sup>3</sup>

D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>4</sup>

D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>4</sup>

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils<sup>4</sup>

D 1587 Practice for Thin-Walled Tube Sampling of Soils<sup>4</sup>

D 2113 Practice for Diamond Core Drilling for Site Investigation<sup>4</sup>

D 2487 Test Method for Classification of Soils for Engineering Purposes<sup>4</sup>

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>4</sup>

D 3282 Practice for Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes<sup>4</sup>

D 3550 Practice for Ring Lined Barrel Sampling of Soils<sup>4</sup>

D 4220 Practice for Preserving and Transporting Soil Samples<sup>4</sup>

## 3. Significance and Use

3.1 An adequately designed and installed ground water monitoring well system for aqueous phase liquids provides essential information for decisions pertaining to one or more of the following subjects:

3.1.1 Aquifer and aquitard properties, both geologic and hydraulic;

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21.05 on Design and Installation of Ground-Water Monitoring Wells.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 04.01.

<sup>3</sup> Annual Book of ASTM Standards, Vol 04.02.

<sup>4</sup> Annual Book of ASTM Standards, Vol 04.08.







3.1.2 Potentiometric surface of a particular hydrologic unit(s);

3.1.3 Water quality with respect to various indicator parameters;

3.1.4 Migration characteristics of a contaminant release;

3.1.5 Additional installations or decommissioning of installations, or both, no longer needed.

#### 4. Terminology

##### 4.1 Definitions:

4.1.1 *annular space; annulus*—the space between two concentric tubes or casings, or between the casing and the borehole wall. This would include the space(s) between multiple strings of tubing/casings in a borehole installed either concentrically or multi-cased adjacent to each other.

4.1.2 *assessment monitoring*—an investigative monitoring program that is initiated after the presence of a contaminant in ground water has been detected. The objective of this program is to determine the concentration of constituents that have contaminated the ground water and to quantify the rate and extent of migration of these constituents.

4.1.3 *ASTM cement types*—Portland cements meeting the requirements of Specifications C 150. Cement types have slightly different formulations that result in various characteristics which address different construction conditions and different physical and chemical environments. They are as follows:

4.1.3.1 *Type I (Portland)*—a general-purpose construction cement with no special properties.

4.1.3.2 *Type II (Portland)*—a construction cement that is moderately resistant to sulfates and generates a lower head of hydration at a slower rate than Type I.

4.1.3.3 *Type III (Portland; high early strength)*—a construction cement that produces a high early strength. This cement reduces the curing time required when used in cold environments, and produces a higher heat of hydration than Type I.

4.1.3.4 *Type IV (Portland)*—a construction cement that produces a low head of hydration (lower than Types I and II) and develops strength at a slower rate.

4.1.3.5 *Type V (Portland)*—a construction cement that is a high sulfate resistant formulation. Used when there is severe sulfate action from soils and ground water.

4.1.4 *bailer*—a hollow tubular receptacle used to facilitate withdrawal of fluid from a well or borehole.

4.1.5 *ballast*—materials used to provide stability to a buoyant object (such as casing within a borehole filled with water).

4.1.6 *blow-in*—the inflow of ground water and unconsolidated material into a borehole or casing caused by differential hydraulic heads; that is, caused by the presence of a greater hydraulic head outside of a borehole/casing than inside.

4.1.7 *borehole* a circular open or uncased subsurface hole created by drilling.

4.1.8 *borehole log*—the record of geologic units penetrated, drilling progress, depth, water level, sample recovery, volumes, and types of materials used, and other significant facts regarding the drilling of an exploratory borehole or well.

DISCUSSION—The definition of aquifer as currently included in Terminology D 653 varies from the definition as prescribed by US

federal regulations. Since this federal definition is associated with the installation of many monitoring wells it is provided herein as a technical note:

*aquifer*—a geologic formation, group of formation, or part of a formation that is saturated, and is capable of providing a significant quantity of water.

4.1.9 *bridge*—an obstruction within the annulus which may prevent circulation or proper emplacement of annular materials.

4.1.10 *casing*—pipe, finished in sections with either threaded connections or bevelled edges to be field welded, which is installed temporarily or permanently to counteract caving, to advance the borehole, or to isolate the zone being monitored, or combination thereof.

4.1.11 *casing, protective*—a section of larger diameter pipe that is emplaced over the upper end of a smaller diameter monitoring well riser or casing to provide structural protection to the well and restrict unauthorized access into the well.

4.1.12 *casing, surface*—pipe used to stabilize a borehole near the surface during the drilling of a borehole that may be left in place or removed once drilling is completed.

4.1.13 *caving; sloughing*—the inflow of unconsolidated material into a borehole which occurs when the borehole walls lose their cohesive strength.

4.1.14 *cement; Portland cement*—commonly known as Portland cement. A mixture that consists of a calcareous, argillaceous, or other silica-, alumina-, and iron-oxide-bearing materials that is manufactured and formulated to produce various types which are defined in Specification C 150. Portland cement is also considered a hydraulic cement because it must be mixed with water to form a cement-water paste that has the ability to harden and develop strength even if cured under water (see *ASTM cement types*).

4.1.15 *centralizer*—a device that assists in the centering of a casing or riser within a borehole or another casing.

4.1.16 *circulation*—applies to the fluid rotary drilling method: drilling fluid movement from the mud pit, through the pump, hose and swivel, drill pipe, annular space in the hole and returning to the mud pit.

4.1.17 *conductance (specific)*—a measure of the ability of the water to conduct an electric current at 77°F (25°C). It is related to the total concentration of ionizable solids in the water. It is inversely proportional to electrical resistance.

4.1.18 *confining unit*—a term that is synonymous with "aquiclude," "aquitard," and "aquifuge;" defined as a body of relatively low permeable material stratigraphically adjacent to one or more aquifers.

4.1.19 *contaminant*—an undesirable substance not normally present in water or soil.

4.1.20 *detection monitoring*—a program of monitoring for the express purpose of determining whether or not there has been a contaminant release to ground water.

4.1.21 *drill cuttings*—fragments or particles of soil or rock, with or without free water, created by the drilling process.

4.1.22 *drilling fluid*—a fluid (liquid or gas) that may be used in drilling operations to remove cuttings from the borehole, to clean and cool the drill bit, and to maintain the integrity of the borehole during drilling.







4.1.23 *d-10*—the diameter of a soil particle (preferably in millimetres) at which 10 % by weight (dry) of the particles of a particular sample are finer. Synonymous with the effective size or effective grain size.

4.1.24 *d-60*—the diameter of a soil particle (preferably in millimetres) at which 60 % by weight (dry) of the particles of a particular sample are finer.

4.1.25 *flow path*—represents the area between two flow lines along which ground water can flow.

4.1.26 *flush joint or flush coupled*—casing or riser with ends threaded such that a consistent inside and outside diameter is maintained across the threaded joints or couplings.

4.1.27 *gravel pack*—common nomenclature for the terminology, primary filter of a well (see *primary filter pack*).

4.1.28 *grout (monitoring wells)*—a low permeability material placed in the annulus between the well casing or riser pipe and the borehole wall (that is, in a single-cased monitoring well), or between the riser and casing (that is, in a multi-cased monitoring well), to maintain the alignment of the casing and riser and to prevent movement of ground water or surface water within the annular space.

4.1.29 *grout shoe*—a plug fabricated of relatively inert materials that is positioned within the lowermost section of a permanent casing and fitted with a passageway, often with a flow check device, through which grout is injected under pressure to fill the annular space. After the grout has set, the grout shoe is usually drilled out.

4.1.30 *head (static)*—the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head.

4.1.31 *head (total)*—the sum of three components at a point: (1) elevation head,  $h_e$ , which is equal to the elevation of the point above a datum; (2) pressure head,  $h_p$ , which is the height of a column of static water than can be supported by the static pressure at the point; and (3) velocity head,  $h_v$ , which is the height the kinetic energy of the liquid is capable of lifting the liquid.

4.1.32 *hydrologic unit*—geologic strata that can be distinguished on the basis of capacity to yield and transmit fluids. Aquifers and confining units are types of hydrologic units. Boundaries of a hydrologic unit may not necessarily correspond either laterally or vertically to lithostratigraphic formations.

4.1.33 *jetting*—when applied as a drilling method, water is forced down through the drill rods or casings and out through the end aperture. The jetting water then transports the generated cuttings to the ground surface in the annulus of the drill rods or casing and the borehole. The term jetting may also refer to a development technique (see well screen jetting).

4.1.34 *loss of circulation*—the loss of drilling fluid into strata to the extent that circulation does not return to the surface.

4.1.35 *mud pit*—usually a shallow, rectangular, open, portable container with baffles into which drilling fluid and cuttings are discharged from a borehole and that serves as a reservoir and settling tank during recirculation of the drilling

fluids. Under some circumstances, an excavated pit with a lining material may be used.

4.1.36 *multi-cased well*—a well constructed by using successively smaller diameter casings with depth.

4.1.37 *neat cement*—a mixture of Portland cement (Specification 150) and water.

4.1.38 *observation well*—typically, a small diameter well used to measure changes in hydraulic heads, usually in response to a nearby pumping well.

4.1.39 *oil air filter*—a filter or series of filters placed in the air flow line from an air compressor to reduce the oil content of the air.

4.1.40 *oil trap*—a device used to remove oil from the compressed air discharged from an air compressor.

4.1.41 *packer (monitoring wells)*—a transient or dedicated device placed in a well that isolates or seals a portion of the well, well annulus, or borehole at a specific level.

4.1.42 *potentiometric surface*—an imaginary surface representing the static head of ground water. The water table is a particular potentiometric surface.

DISCUSSION—Where the head varies with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer. More than one potentiometric surface is required to describe the distribution of head in this case.

4.1.43 *primary filter pack*—a clean silica sand or sand and gravel mixture of selected grain size and gradation that is installed in the annular space between the borehole wall and the well screen, extending an appropriate distance above the screen, for the purpose of retaining and stabilizing the particles from the adjacent strata. The term is used in place of *gravel pack*.

4.1.44 *PTFE tape*—joint sealing tape composed of polytetrafluoroethylene.

4.1.45 *riser*—the pipe extending from the well screen to or above the ground surface.

4.1.46 *secondary filter pack*—a clean, uniformly graded sand that is placed in the annulus between the primary filter pack and the over-lying seal, or between the seal and overlying grout backfill, or both, to prevent movement of seal or grout, or both, into the primary filter pack.

4.1.47 *sediment sump*—a blank extension beneath the well screen used to collect fine-grained material from the filter pack and adjacent strata. The term is synonymous with rat trap or tail pipe.

4.1.48 *shear strength (monitoring wells)*—a measure of the shear or gel properties of a drilling fluid or grout.

4.1.49 *single-cased well*—a monitoring well constructed with a riser but without an exterior casing.

4.1.50 *static water level*—the elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping or conditions related to well installation, hydrologic testing, or nearby pumpage.

4.1.51 *tamper*—a heavy cylindrical metal section of tubing that is operated on a wire rope or cable. It slips over the riser and fits inside the casing or borehole annulus. It is generally used to tamp annular sealants or filter pack materials into place and prevent bridging.

4.1.52 *target monitoring zone*—the ground water flow path from a particular area or facility in which monitoring wells will be screened. The target monitoring zone should be







a stratum (strata) in which there is a reasonable expectation that a vertically placed well will intercept migrating contaminants.

4.1.53 *test pit*—a shallow excavation made to characterize the subsurface.

4.1.54 *transmissivity*—the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

DISCUSSION—It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

4.1.55 *tremie pipe*—a pipe or tube that is used to transport filter pack materials and annular sealant materials from the ground surface into the borehole annulus or between casings and casings or riser pipe of a monitoring well.

4.1.56 *uniformly graded*—a quantitative definition of the particle size distribution of a soil which consists of a majority of particles being of the same approximate diameter. A granular material is considered uniformly graded when the uniformity coefficient is less than about five (Test Method D 2487). Comparable to the geologic term *well sorted*.

4.1.57 *vented cap*—a cap with a small hole that is installed on top of the riser.

4.1.58 *washout nozzle*—a tubular extension with a check valve utilized at the end of a string of casing through which water can be injected to displace drilling fluids and cuttings from the annular space of a borehole.

4.1.59 *weep hole*—a small diameter hole (usually 1/4 in.) drilled into the protective casing above the ground surface that serves as a drain hole for water that may enter the protective casing annulus.

4.1.60 *well completion diagram*—a record that illustrates the details of a well installation.

4.1.61 *well screen*—a filtering device used to retain the primary or natural filter pack; usually a cylindrical pipe with openings of a uniform width, orientation, and spacing.

4.1.62 *well screen jetting (hydraulic jetting)*—when jetting is used for development, a jetting tool with nozzles and a high-pressure pump is used to force water outwardly through the screen, the filter pack, and sometimes into the adjacent geologic unit.

4.1.63 *zone of saturation*—a hydrologic zone in which all the interstices between particles of geologic material or all of the joints, fractures, or solution channels in a consolidated rock unit are filled with water under pressure greater than that of the atmosphere.

## 5. Site Characterization

5.1 *General*—Soil mechanics, geomorphological concepts, geologic structure, stratigraphy, and sedimentary concepts, as well as the nature and behavior of the solutes of interest, must be combined with a knowledge of ground water movement to make a complete application of the results of the monitoring well design and installation guidance. Therefore, development of a conceptual hydrogeologic model that identifies potential flow paths and the target monitoring zone(s) is recommended prior to monitoring well design and installation. Development of the conceptual model is accomplished in two phases—an initial reconnaissance and a field investigation. When the hydrogeology of a project area is relatively uncomplicated and well docu-

mented in the literature, the initial reconnaissance may provide sufficient information to identify flow paths and the target monitoring zone(s). However, where little background data is available or the geology is complicated, a field investigation will generally be necessary to completely develop a conceptual hydrogeologic model.

5.2 *Initial Reconnaissance of Project Area*—The goal of the initial reconnaissance of the project area is to identify and locate those zones with the greatest potential to transmit a fluid from the project area. Identifying these flow paths is the first step in selecting the target ground water monitoring zone(s).

5.2.1 *Literature Search*—Every effort should be made to collect and review all applicable field and laboratory data from previous investigations of the project area. Data such as, but not limited to, topographic maps, aerial imagery, site ownership and utilization records, geologic and hydrogeologic maps and reports, mineral resource surveys, water well logs, personal information from local well drillers, agricultural soil reports, geotechnical engineering reports, and other engineering maps and report related to the project area should be reviewed.

5.2.2 *Field Reconnaissance*—Early in the investigation, the soil and rocks in open cut areas in the vicinity of the project should be studied, and various soil and rock profiles noted. Special consideration should be given to soil color and textural changes, landslides, seeps, and springs within or near the project area.

5.2.3 *Preliminary Conceptual Model*—The distribution of the predominant soil and rock units likely to be found during subsurface exploration may be hypothesized at this time in a preliminary hydrogeologic conceptual model using data obtained in the literature search and field reconnaissance. In areas where the geology is relatively uniform, well documented in the literature, and substantiated by the field reconnaissance, further refinement of the conceptual model may not be necessary unless anomalies are discovered in the well drilling stage.

5.3 *Field Investigation*—The goal of the field investigation is to refine the preliminary conceptual hydrogeologic model so that the target monitoring zone(s) is selected prior to monitoring well installation.

5.3.1 *Exploratory Borings and Test Pits*—Characterization of the flow paths conceptualized in the initial reconnaissance involves defining the porosity, hydraulic conductivity, gradation, stratigraphy, lithology, and structure of each hydrologic unit. The characteristics are defined by conducting an exploratory boring program which may include test pits. Exploratory borings and test pits should be deep enough to develop the required engineering and hydrogeologic data for determining the flow path(s), target monitoring zone, or both.

5.3.1.1 *Sampling*—Soil and rock properties should not be predicted wholly on field identification or classification, but should be checked by laboratory and field tests made on samples. Representative soil or rock samples, or both, of each material that is significant to the analysis and design of the monitoring system should be obtained and evaluated by a geologist, hydrogeologist, or engineer trained and experienced in soil and rock analysis. Soil sample extraction should be conducted according to Practice D 1452, Method D 1586.







Practice D 3550, or Practice D 1587, whichever is appropriate given the anticipated characteristics of the soil samples. Rock samples should be extracted according to Practice D 2113. Soil samples obtained for evaluation of hydraulic properties should be containerized and identified for shipment to a laboratory. Special measures to preserve either the continuity of the sample or the natural moisture are not usually required. However, soil and rock samples obtained for evaluation of chemical properties often require special field preparation and preservation to prevent significant alteration of the chemical constituents during transportation to a laboratory (see Practice D 4220). Rock samples for evaluation of hydraulic properties are usually obtained using a split-inner-tube core barrel. Evaluation and logging of the core samples is usually made in the field before the core is removed from half of the split inner tube core barrel.

**5.3.1.2 Boring Logs**—Care should be taken to prepare and retain a complete boring log and sampling record for each exploratory borehole and test pit.

**NOTE 1**—Site investigations for the installation of ground-water monitoring wells can vary greatly due to the availability of reliable site data or the lack thereof. The general procedure would however be as follows: (1) gather factual data regarding the surficial and subsurface conditions, (2) analyze the data, (3) develop a conceptual model of the site conditions, (4) locate the monitoring wells based on the first three steps. Monitoring wells should only be installed with sufficient understanding of the geologic and hydrogeologic conditions present on site. Monitoring wells often serve as part of an overall site investigation for a specific purpose, such as determining the extent of contamination present, or for prediction of the effectiveness of aquifer remediations. In these cases extensive additional geotechnical and hydrogeologic information may be required that would go beyond the Section 5 Site Characterization description.

Boring logs should include the location, geotechnical (that is, penetration rates or blow counts), and sampling information for each material identified in the borehole either by symbol or word description, or both. Identification of all soils should be in accordance with Practice D 2488 or Practice D 3282. Identification of rock material should be based on Nomenclature C 294 or by an appropriate geologic classification system. Observations of seepage, free water, and water levels should also be noted. The boring logs should be accompanied by a report that includes a description of the area investigated; a map illustrating the vertical and horizontal location (with reference to nearest National Geodetic Vertical Datum [NGVD] and to a standardized survey grid, respectively) of each exploratory borehole or test pit, or both; and color photographs of rock cores, soil samples, and exposed strata labeled with a date and identification.

**5.3.2 Geophysical Exploration**—Geophysical surveys may be used to supplement borehole and outcrop data and to aid in interpretation between boreholes. Surface geophysical methods such as seismic surveys, and electrical-resistivity and electromagnetic conductance surveys can be particularly valuable when distinct differences in the properties of contiguous subsurface materials are indicated. Borehole methods such as resistivity, gamma, gamma-gamma, neutron, and caliper logs can be useful to confirm specific subsurface geologic conditions. Gamma logs are particularly useful in existing cased wells.

**5.3.3 Ground Water Flow Direction**—Ground water flow direction is generally determined by measuring the vertical

and horizontal hydraulic gradient within each conceptualized flow path. However, because water will flow along the path of least resistance, flow direction may be oblique to the hydraulic gradient (buried stream channels or glacial valleys, for example). Flow direction is determined by first installing piezometers in the exploratory boreholes. The depth and location of the piezometers will depend upon anticipated hydraulic connections between conceptualized flow paths and their respective lateral direction of flow. Following careful evaluation, it may be possible to utilize existing private or public wells to obtain water level data. The construction integrity of such wells should be verified to ensure that the water levels obtained from the wells are representative only of the zones of interest. Following water level data acquisition, a potentiometric surface map should be prepared. Flow paths are ordinarily determined to be at right angles, or nearly so, to the equipotential lines.

**5.4 Completing the Conceptual Model**—A series of hydrogeologic cross sections should be developed to refine the conceptual model. This is accomplished by first plotting logs of soil and rock observed in the exploratory borings or test pits, and interpreting between these logs using the geologic and engineering interrelationships between other soil and rock data observed in the initial reconnaissance or with geophysical techniques. Extrapolation of data into adjacent areas should be done only where geologically uniform subsurface conditions are known to exist. The next step is to integrate the profile data with the piezometer data for both vertical and horizontal hydraulic gradients. Plan view and cross-sectional flow nets may need to be constructed. Following the analysis of these data, conclusions can be made as to which flow path(s) is the appropriate target monitoring zone(s).

**NOTE 2**—Ground water monitoring is difficult and may not be a reliable technology in fine-grain, low hydraulic conductivity, primary porosity strata because of (1) the disproportionate influence that microstratigraphy has on ground water flow in fine-grain strata; (2) flow lines proportionally higher for the vertical flow component in low hydraulic conductivity strata; and (3) the presence of indigenous metallic and inorganic constituents that make water quality data evaluation difficult.

## 6. Monitoring Well Construction Materials

**6.1 General**—The materials that are used in the construction of a monitoring well and that come in contact with the water sample should not measurably alter the chemical quality of the sample for the constituents being examined using the appropriate sampling protocols. Furthermore, the riser, well screen, and annular sealant injection equipment should be steam cleaned or high-pressure water cleaned (if appropriate for the selected riser material) immediately prior to well installation or certified clean from the manufacturer and delivered to site in a protective wrapping. Samples of the cleaning water, filter pack, annular seal, and mixed grout should be retained to serve as quality control until the completion of at least one round of ground water quality sampling and analysis.

**6.2 Water**—Water used in the drilling process, to prepare grout mixtures and to decontaminate the well screen, riser, and annular sealant injection equipment, should be obtained from a source of known chemistry that does not contain







constituents that could compromise the integrity of the well installation.

### 6.3 Primary Filter Pack:

**6.3.1 Materials**—The primary filter pack (gravel pack) consists of a granular material of known chemistry and selected grain size and gradation that is installed in the annulus between the screen and the borehole wall. The filter pack is usually selected to have a 30 % finer (d-30) grain size that is about 4 to 10 times greater than the 30 % finer (d-30) grain size of the hydrologic unit being filtered (see Fig. 1). Usually, the filter is selected to have a low (that is, less than 2.5) uniformity coefficient. The grain size and gradation of the filter are selected to stabilize the hydrologic unit adjacent to the screen and permit only the finest soil grains to enter the screen during development. Thus, after development, a correctly filtered monitoring well is relatively turbid-free.

**NOTE 3**—When installing a monitoring well in Karst or highly fractured bedrock, the borehole configuration of void spaces within the formation surrounding the borehole is often unknown. Therefore, the installation of a filter pack becomes difficult and may not be possible.

**6.3.2 Gradation**—The filter pack should be uniformly graded and comprised of hard durable siliceous particles washed and screened with a particle size distribution derived by multiplying the d-30 size of the finest-grained screened stratum by a factor between 4 and 10. Use a number between four and six as the multiplier if the stratum is fine and uniform; use a factor between six and ten where the material has highly nonuniform gradation and includes silt-sized particles. The grain-size distribution of the filter pack is then plotted using the d-30 size as the control point on the graph. The selected filter pack should have a uniformity coefficient of approximately 2.5 or less.

**NOTE 4**—This practice presents a design for monitoring wells that will be effective in the majority of aquifers. Applicable state guidance may differ from the designs contained in this practice.

**NOTE 5**—Because the well screen slots have uniform openings, the filter pack should be composed of particles that are as uniform in size as is practical. Ideally, the uniformity coefficient (the quotient of the 60 % passing, D-60 size divided by the 10 % passing D-10 size [effective size]) of the filter pack should be 1.0 (that is, the D-60 % and the D-10 % sizes should be identical). However, a more practical and consistently achievable uniformity coefficient for all ranges of filter pack sizes is 2.5. This value of 2.5 should represent a maximum value, not an ideal.

**NOTE 6**—Although not recommended as standard practice, often a project requires drilling and installing the well in one phase of work.

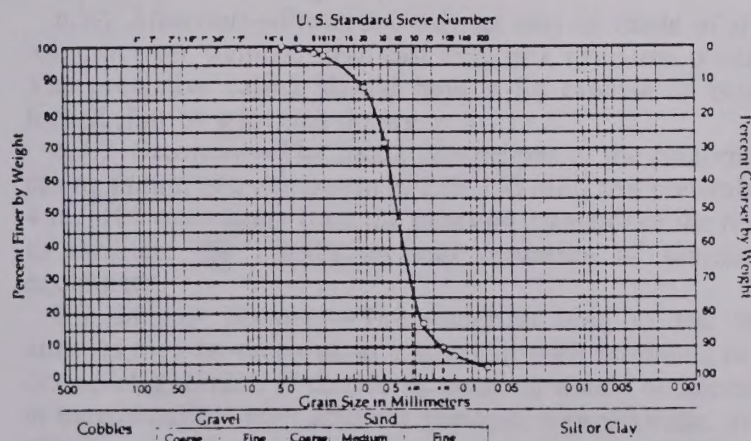


FIG. 1 Example Grading Curve for Design of Monitoring Well Screens

Therefore, the filter pack materials must be ordered and delivered to the drill site before soil samples can be collected. In these cases, the suggested well screen slot size and filter pack materials are presented in Table 1.

### 6.4 Well Screen:

**6.4.1 Materials**—The well screen should be new, machine-slotted or continuous wrapped wire-wound and composed of materials most suited for the monitoring environment and site characterization findings. The screen should be plugged at the bottom. The plug should be of the same material as the well screen. This assembly must have the capability to withstand installation and development stresses without becoming dislodged or damaged. The length of the slotted area should reflect the interval to be monitored. Immediately prior to installation, the well screen should be steam cleaned or high-pressure water cleaned (if appropriate for the selected well screen materials) with water from a source of known chemistry if not certified by the manufacturer, delivered, and maintained clean at the site.

**NOTE 7**—Well screens are most commonly composed of PVC, stainless steel, fiberglass, or fluoropolymer materials.

**6.4.2 Diameter**—The minimum nominal internal diameter of the well screen should be chosen based on the particular application. However, in most instances, a minimum of 2 in. (50 mm) is needed to allow for the introduction and withdrawal of sampling devices.

**6.4.3 Slot Size**—The slot size of the well screen should be determined relative to the grain size analysis of the stratum interval to be monitored and the gradation of the filter pack material. In granular non-cohesive strata that will fall in easily around the screen, filter packs are not necessary. In these cases of natural development, the slot size of the well screen is to be determined using the grain size of the materials in the surrounding strata. The slot size and arrangement should retain at least 90 % and preferably 99 % of the filter pack. The method for determining the correct gradation of filter pack material is described in 6.3.2.

### 6.5 Riser:

**6.5.1 Materials**—The riser should be new and composed of materials that will not alter the quality of water samples for the constituents of concern and that are appropriate for the monitoring environment. The riser should have adequate wall thickness and coupling strength to withstand installation and development stresses. Each section of riser should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known chemistry immediately prior to installation.

**NOTE 8**—Risers are generally constructed of PVC, stainless steel, fiberglass, or fluoropolymer materials.

**6.5.2 Diameter**—The minimum nominal internal diameter of the riser should be chosen based on the particular application. However, in most instances, a minimum of 2 in. (50 mm) is needed to accommodate sampling devices.

**6.5.3 Joints (Couplings)**—Threaded joints are recommended. Glued or solvent welded joints of any type are *not* recommended since glues and solvents may alter the chemistry of the water samples. In most cases, square profile flush joint threads do not require PTFE taping, however, tapered thread joints should be PTFE taped to prevent leakage of water into the riser. Alternatively, O-rings composed of







**TABLE 1 Recommended (Achievable) Filter Pack Characteristics for Common Screen Slot Sizes**

Size of Screen Opening, mm (in.)	Slot No.	Sand Pack Mesh Size Name(s)	1 % Passing Size (D-1), mm	Effective Size, (D-10), mm	30 % Passing Size (D-30), mm	Range of Uniformity Coefficient	Roundness (Powers Scale)
0.125 (0.005)	5 <sup>A</sup>	100	0.09 to 0.12	0.14 to 0.17	0.17 to 0.21	1.3 to 2.0	2 to 5
0.25 (0.010)	10	20 to 40	0.25 to 0.35	0.4 to 0.5	0.5 to 0.6	1.1 to 1.6	3 to 5
0.50 (0.020)	20	10 to 20	0.7 to 0.9	1.0 to 1.2	1.2 to 1.5	1.1 to 1.6	3 to 6
0.75 (0.030)	30	10 to 20	0.7 to 0.9	1.0 to 1.2	1.2 to 1.5	1.1 to 1.6	3 to 6
1.0 (0.040)	40	8 to 12	1.2 to 1.4	1.6 to 1.8	1.7 to 2.0	1.1 to 1.6	4 to 6
1.5 (0.060)	60	6 to 9	1.5 to 1.8	2.3 to 2.8	2.5 to 3.0	1.1 to 1.7	4 to 6
2.0 (0.080)	80	4 to 8	2.0 to 2.4	2.4 to 3.0	2.6 to 3.1	1.1 to 1.7	4 to 6

<sup>A</sup> A 5-slot (0.152-mm) opening is not currently available in slotted PVC but is available in Vee wire PVC and Stainless; 6-slot opening may be substituted in these cases.

materials that would not impact the water sample for the constituents of concern may be selected for use on flush joint threads.

**6.6 Casing**—Where conditions warrant, the use of permanent casing installed to prevent communication between water-bearing zones is encouraged. The following subsections address both temporary and permanent casings.

**6.6.1 Materials**—The material type and minimum wall thickness of the casing should be adequate to withstand the forces of installation. All casing that is to remain as a permanent part of the installation (that is, multi-cased wells) should be new and cleaned to be free of interior and exterior protective coatings.

**NOTE 9**—The exterior casing (temporary or permanent multi-cased) is generally composed of steel, although other appropriate materials may be used.

**6.6.2 Diameter**—Several different casing sizes may be required depending on the subsurface geologic conditions penetrated. The diameter of the casing for filter packed wells should be selected so that a minimum annular space of 2 in. (50 mm) is maintained between the inside diameter of the casing and outside diameter of the riser. In addition, the diameter of the casings in multi-cased wells should be selected so that a minimum annular space of 2 in. is maintained between the casing and the borehole (that is, a 2-in. diameter screen will require first setting a 6-in. (152-mm) diameter casing in a 10-in. (254-mm) diameter boring).

**NOTE 10**—Under difficult drilling conditions (collapsing soils, rock, or cobbles), it may be necessary to advance temporary casing, under these conditions a smaller annular space may be maintained.

**6.6.3 Joints (Couplings)**—The ends of each casing section should be either flush-threaded or bevelled for welding.

#### 6.7 Protective Casing:

**6.7.1 Materials**—Protective casings may be made of aluminum, steel, stainless steel, cast iron, or a structural plastic. The protective casing should have a lid capable of being locked shut by a locking device.

**6.7.2 Diameter**—The inside dimensions of the protective casing should be a minimum of 2 in. (50 mm) and preferably 4 in. (101 mm) larger than the nominal diameter of the riser to facilitate the installation and operation of sampling equipment.

**6.8 Annular Sealants**—The materials used to seal the annulus may be prepared as a slurry or used un-mixed in a dry pellet, granular, or chip form. Sealants should be selected to be compatible with ambient geologic, hydrogeologic, and climatic conditions and any man-induced conditions anticipated to occur during the life of the well.

**6.8.1 Bentonite**—Bentonite should be powdered, gran-

ular, pelletized, or chipped sodium montmorillonite furnished in sacks or buckets from a commercial source and free of impurities which adversely impact the water quality in the well. Pellets consist of roughly spherical or disk shaped units of compressed bentonite powder. Chips are large, irregularly shaped, and coarse granular units of bentonite free of additives. The diameter of pellets or chips selected for monitoring well construction should be less than one fifth the width of the annular space into which they are placed to reduce the potential for bridging. Granules consist of coarse particles of unaltered bentonite, typically smaller than 0.2 in. (50 mm).

**6.8.2 Cement**—Each type of cement has slightly different characteristics that may be appropriate under various physical and chemical conditions. Cement should be one of the five Portland cement types that are specified in Specification C 150. The use of quick-setting cements containing additives is not recommended for use in monitoring well installation. Additives may leach from the cement and influence the chemistry of the water samples.

**6.8.3 Grout**—The grout backfill that is placed above the bentonite annular seal and secondary filters (see Fig. 2) is ordinarily a liquid slurry consisting of either a bentonite (powder or granules, or both) base and water, or a Portland cement base and water. Often, bentonite-based grouts are used when it is desired that the grout remain flexible (that is, to accommodate freeze-thaw) during the life of the installation. Cement or bentonite-based grouts are often used when the filling in of cracks in the surrounding geologic material, adherence to rock units, or a rigid setting is desired.

**6.8.3.1 Mixing**—The mixing (and placing) of a grout backfill should be performed with precisely recorded weights and volumes of materials, and according to procedures stipulated by the manufacturer that often include the order of component mixing. The grout should be thoroughly mixed with a paddle type mechanical mixer or by recirculating the mix through a pump until all lumps are disintegrated. Lumpy grout should not be used in the construction of a monitoring well to prevent bridging within the tremie.

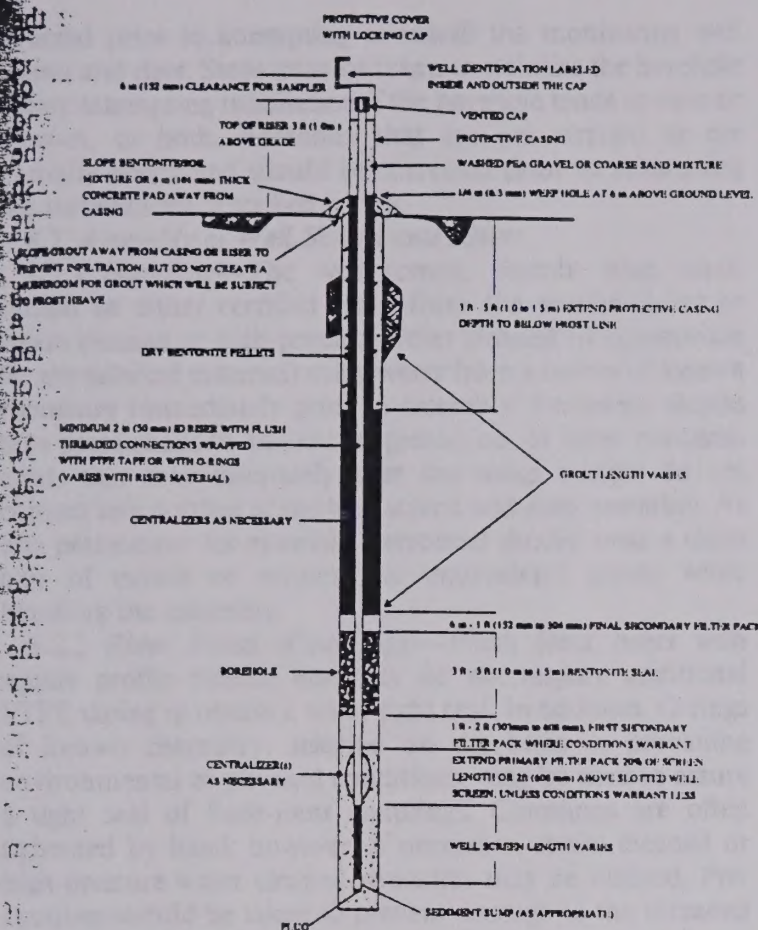
**NOTE 11**—Lumps do not include lost circulation materials that may be added to the grout if excessive grout losses occur.

**6.8.3.2 Typical Bentonite Base Grout**—When a bentonite base grout is used, bentonite, usually unaltered, *must* be the first additive placed in the water through a venturi device. A typical unbeneficiated bentonite base grout consists of about 1 to 1.25 lb (0.57 kg) of unaltered bentonite to each 1 gal (3.8 L) of water. After the bentonite is mixed and allowed to “yield or hydrate,” up to 2 lb (0.9 kg) of Type I Portland cement (per gallon of water) is often added to stiffen the mix.









**FIG. 2 Monitoring Well Design—Single-Cased Well**

100 % Bentonite grouts should not be used solely for monitoring well annular sealants in the vadose zone of arid regions because of their propensity to desiccate. This could result in non-representative waters affecting the target monitoring zone.

NOTE 12—High solids bentonite grouts (minimum 20 % by weight with water) and other bentonite-based grouts may contain granular bentonite to increase the solids content and other components added under manufacturer's directions to either stiffen or retard stiffening of the mix.

*All additives to grouts should be evaluated for their effects on subsequent water samples.*

**6.8.3.3 Typical Cement Base Grout**—When a cement-based grout is used, cement is usually the first additive placed in the water. A typical cement-based grout consists of about 6 to 7 gal (23 to 26 L) of water per 94-lb (43-kg) bag of Type I Portland cement. From 0 to 10 % (by dry weight of cement) of unaltered bentonite powder is often added after the initial mixing of cement and water to retard shrinkage and provide plasticity. The bentonite is added *dry* to the cement-water slurry without first mixing it with water.

### 6.9 Secondary Filter Packs:

**6.9.1 Materials**—A secondary filter pack is a layer of material placed in the annulus between the primary filter pack and the bentonite seal, and between the bentonite seal and the grout backfill (see Figs. 2 and 3).

6.9.2 *Gradation*—The secondary filter pack should be uniformly graded fine sand with a 100 % by weight passing the No. 30 U.S. Standard sieve, and less than 2 % by weight passing the 200 U.S. Standard sieve.

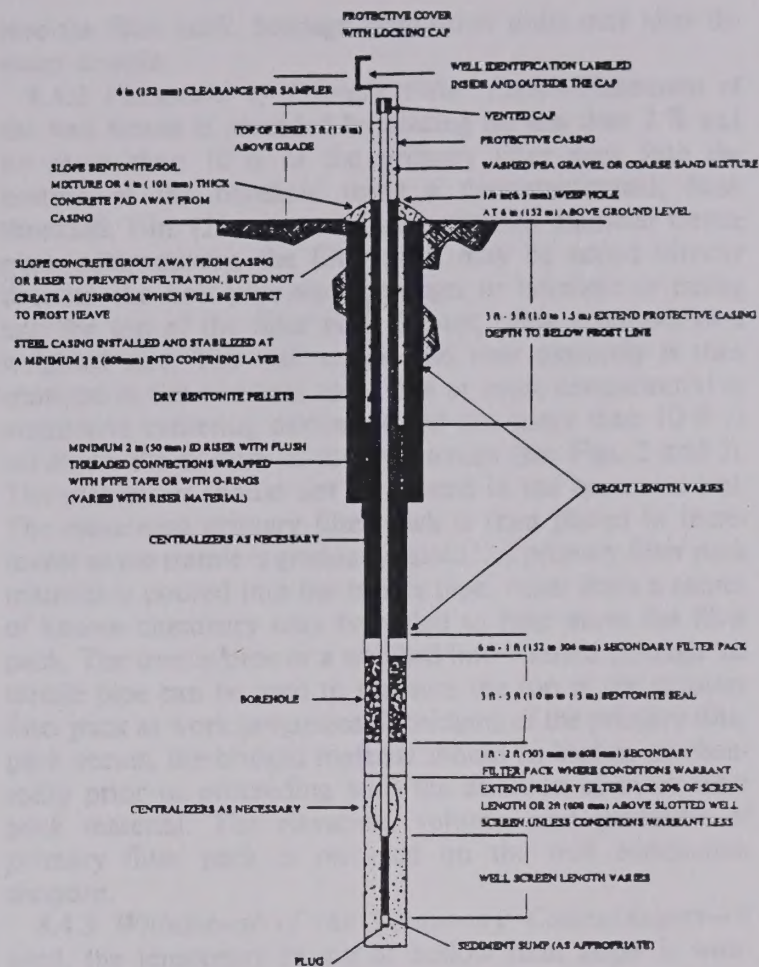


FIG. 3 Monitoring Well Design—Multi-Cased Well

**6.10 Annular Seal Equipment**—The equipment used to inject the annular seals and filter pack should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known quality prior to use. This procedure is performed to prevent the introduction of materials that may ultimately alter the water sample quality.

## 7. Drilling Methods

7.1 The type of equipment required to create a stable, open, vertical borehole for installation of a monitoring well depends upon the site geology, hydrology, and the intended use of the data. Engineering and geological judgment is required for the selection of the drilling methods utilized for drilling the exploratory boreholes and monitoring wells. Whenever feasible, drilling procedures should be utilized that do not require the introduction of water or liquid fluids into the borehole, and that optimize cuttings control at ground surface. Where the use of drilling fluid is unavoidable, the selected fluid should have as little impact as possible on the water samples for the constituents of interest. In addition, care should be taken to remove as much drilling fluid as possible from the well and the aquifer during the well development process. It is recommended that if an air compressor is used, it is equipped with an oil air filter or oil trap.

## 8. Monitoring Well Installation

8.1 *Stable Borehole*—A stable borehole must be con-







structed prior to attempting to install the monitoring well screen and riser. Steps must be taken to stabilize the borehole before attempting installation if the borehole tends to cave or blow-in, or both. Boreholes that are not straight or are partially obstructed should be corrected prior to attempting the installations described herein.

### 8.2 *Assembly of Well Screen and Riser:*

8.2.1 *Handling*—The well screen, bottom plug, riser, should be either certified clean from the manufacturer or steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known chemistry immediately prior to assembly. Personnel should take precautions to assure that grease, oil, or other contaminants that may ultimately alter the water sample do not contact any portion of the well screen and riser assembly. As one precaution, for example, personnel should wear a clean pair of cotton or surgical (or equivalent) gloves while handling the assembly.

8.2.2 *Riser Joints (Couplings)*—Flush joint risers with square profile threads normally do not require additional PTFE taping to obtain a water tight seal. In addition, O-rings of known chemistry, selected on the basis of prevailing environmental or physical conditions, may be used to assure a tight seal of flush-joint couplings. Couplings are often tightened by hand; however, if necessary, steam cleaned or high-pressure water cleaned wrenches may be utilized. Precautions should be taken to prevent damage to the threaded joints during installation.

8.3 *Setting the Well Screen and Riser Assembly*—When the well screen and riser assembly is lowered to the predetermined level and held into position, the assembly may require ballast to counteract the tendency to float in the borehole. Ballasting may be accomplished by continuously filling the riser with water from a source of known chemistry or, preferably, water which was previously removed from the borehole. Alternatively, the riser may be slowly pushed into the fluid in the borehole with the aid of hydraulic rams on the drill rig and held in place as additional sections of riser are added to the column. Care must be taken to secure the riser assembly so that personnel safety is assured during the installation. The assembly must be installed straight with the appropriate centralizers to allow for the introduction and withdrawal of sampling devices. Difficulty in maintaining a straight installation may be encountered where the weight of the well screen and riser assembly is significantly less than the buoyant force of the fluid in the borehole. The riser should extend above grade and be capped temporarily to deter entrance of foreign materials during completion operations.

### 8.4 *Installation of the Primary Filter Pack:*

8.4.1 *Volume of Filter Pack*—The volume of filter pack required to fill the annular space between the well screen and borehole should be computed, measured, and recorded on the well completion diagram during installation. To be effective, the filter pack should extend above the screen for a distance of about 20 % of the length of the well screen but not less than 2 ft (600 mm) (see Figs. 2 and 3). Where there is hydraulic connection between the zone to be monitored and the overlying strata, this upward extension should be gauged to prevent seepage from overlying hydrologic units

into the filter pack. Seepage from other units may alter the water sample.

8.4.2 *Placement of Primary Filter Pack*—Placement of the well screen is preceded by placing no less than 2 % and no more than 10 % of the primary filter pack into the bottom of the borehole using a decontaminated, flush threaded, 1-in. (25-mm) minimum internal diameter tremie pipe. Alternatively, the filter pack may be added directly between the riser pipe and the auger or borehole or casing and the top of the filter pack located using a tamper or a weighted line. The well screen and riser assembly is then centered in the borehole using one or more centralizer(s) or alternative centering device located not more than 10 ft (3 m) above the bottom of the well screen (see Figs. 2 and 3). The centralizer should not be located in the bentonite seal. The remaining primary filter pack is then placed in increments as the tremie is gradually raised. As primary filter pack material is poured into the tremie pipe, water from a source of known chemistry may be added to help move the filter pack. The tremie pipe or a weighed line inserted through the tremie pipe can be used to measure the top of the primary filter pack as work progresses. If bridging of the primary filter pack occurs, the bridged material should be broken mechanically prior to proceeding with the addition of more filter pack material. The elevation, volume, and gradation of primary filter pack is recorded on the well completion diagram.

8.4.3 *Withdrawal of the Temporary Casing/Augers*—If used, the temporary casing or hollow stem auger is withdrawn, usually in stipulated increments. Care should be taken to minimize lifting the riser with the withdrawal of the temporary casing/augers. To limit borehole collapse, the temporary casing or hollow stem auger is usually withdrawn until the lower most point on the temporary casing or hollow stem auger is at least 2 ft (608 mm), but no more than 5 ft (1.5 m), above the filter pack for unconsolidated materials; or at least 5 ft, but no more than 10 ft (3.0 m), for consolidated materials. In highly unstable formations, withdrawal intervals may be much less. After each increment, it should be ascertained that the primary filter pack has not been displaced during the withdrawal operation (that is, a weighed measuring device).

8.5 *Placement of First Secondary Filter*—A secondary filter pack may be installed above the primary filter pack to prevent the intrusion of the bentonite grout seal into the primary filter pack (see Figs. 2 and 3). To be effective, measured and recorded volume of secondary filter material should be added to extend 1 to 2 ft (304 to 608 mm) above the primary filter pack. As with the primary filter, a secondary filter must not extend into an overlying hydrologic unit (see 8.4.1). The well designer should evaluate the need for this filter pack by considering the gradation of the primary filter pack, the hydraulic heads between adjacent units, and the potential for grout intrusion into the primary filter pack. The secondary filter material is poured into the annular space through a decontaminated, flush threaded, 1-in. (25-mm) minimum internal diameter tremie pipe lowered to within 3 ft (1.0 m) of the placement interval. Water from a source of known chemistry may be added to help move the filter pack into its proper location. The tremie pipe or weighed line inserted through the tremie pipe can be







used to measure the top of the secondary filter pack as work progresses. The elevation, volume, and gradation of the secondary filter pack is recorded on the well completion diagram.

**8.6 Installation of the Bentonite Seal**—A bentonite pellet or a slurry seal is placed in the annulus between the borehole and the riser pipe on top of the secondary or primary filter pack (see Figs. 2 and 3). This seal retards the movement of cement-based grout backfill into the primary or secondary filter packs. To be effective, the bentonite seal should extend above the filter packs approximately 3 to 5 ft (1.0 to 1.5 m)—depending on local conditions. The bentonite seal should be installed using a tremie pipe lowered to the top of the filter packs and slowly raised as the bentonite pellets or the slurry fill the annular space. Bentonite pellets may bridge and block the tremie pipe in deep wells. In these cases, pellets may be allowed to free-fall into the borehole. As a bentonite pellet seal is poured into the tremie pipe or allowed to free-fall into the borehole, a tamper or weighed line may be necessary to tamp pellets into place. If the seal is installed above the water level, water from a source of known chemistry would be added to allow proper hydration of the annular seal. The tremie pipe or a weighed line inserted through the tremie pipe can be used to measure the top of the bentonite seal as the work progresses. If a bentonite pellet seal is being constructed above the water level, approximately 5 gal (20 L) of water from a source of known chemistry can be poured into the annulus to ensure that the pellets hydrate. Sufficient time should be allowed for the bentonite pellet seal to hydrate or the slurry annular seal to expand prior to grouting the remaining annulus. The volume and elevation of the bentonite seal material should be measured and recorded on the well completion diagram.

**8.7 Final Secondary Filter Pack**—A 6-in. to 1-ft (152 to 304-mm) secondary filter may be placed above the bentonite seal in the same manner described in 8.5 (see Figs. 2 and 3). This secondary filter pack will provide a confining layer over the bentonite seal to limit the downward movement of cement-based grout backfill into the bentonite seal. The volume, elevation, and gradation of this final secondary filter pack should be documented on the well completion diagram.

#### 8.8 Grouting the Annular Space:

**8.8.1 General**—Grouting procedures vary with the type of well design. The following procedures will apply to both single- and multi-cased monitoring wells. Paragraphs 8.8.2 and 8.8.3 detail those procedures unique to single- and multi-cased installations, respectively.

**8.8.1.1 Volume of Grout**—The volume and location of grout used to backfill the remaining annular space is recorded on the well completion diagram. An ample volume of grout should be premixed on site to compensate for unexpected losses. The use of alternate grout materials, including grouts containing gravel, may be necessary to control zones of high grout loss.

**8.8.1.2 Injection Procedures**—The grout backfill should be injected under pressure to reduce the chance of leaving voids in the grout, and to displace any liquids and drill cuttings that may remain in the annulus. Depending upon the well design, grouting may be accomplished using a pressure grouting technique or by gravity feed through a tremie pipe. With either method, grout is introduced in one

continuous operation until full strength grout flows out at the ground surface without evidence of drill cuttings or fluid. The grout should slope away from the riser or casing at the surface, but care should be taken not to create a grout mushroom that would be subjected to frost heave.

**8.8.1.3 Grout Setting and Curing**—The riser or casing or both should not be disturbed until the grout sets and cures for the amount of time necessary to prevent a break in the seal between the grout and riser or grout and casing or both. The amount of time required will vary with grout content and climatic conditions and should be documented on the well completion diagram.

**8.8.2 Specific Procedures for Single-Cased Wells**—Grouting should begin at a level directly above the final secondary filter pack (see Fig. 2). Grout should be injected using a tremie pipe equipped with a side discharge; this dissipates the fluid-pumping energy against the borehole wall and riser, reducing the potential for infiltration of grout into the primary filter pack. The tremie pipe should be kept full of grout from start to finish with the discharge end of the pipe completely submerged as it is slowly and continuously lifted. Approximately 5 to 10 ft (1.5 to 3.0 m) of tremie pipe should remain submerged until grouting is complete. For deep installations or where the joints or couplings of the selected riser cannot withstand the shear or collapse stress exerted by a full column of grout as it sets, a staged grouting procedure may be considered. If used, the temporary casing or hollow stem auger should be removed in increments immediately following each increment of grout installation and in advance of the time when the grout begins to set. If casing removal does not commence until grout injection is completed, then, after the casing is removed, additional grout may be periodically injected into the annular space to maintain a continuous column of grout up to the ground surface.

**8.8.3 Specific Procedures for Multi-Cased Wells**—If the outer casing of a multi-cased well cannot be driven to form a tight seal between the surrounding stratum (strata) and the casing, it should be installed in a predrilled borehole. After the borehole has penetrated not less than 2 ft (608 mm) of the first targeted confining stratum, the outer casing is lowered to the bottom of the boring and the annular space is filled with grout. Grouting may be accomplished using a pressure grouting method or gravity feed through a tremie pipe. Pressure grouting will require the use of a grout shoe or packer installed at the end of the outer casing to prevent grout from moving up into the casing. If a tremie pipe is used to inject grout into the annular space, it should be equipped with a side discharge. With each alternative, the grout must be allowed to cure and form a seal between the casing and the grout prior to advancing the hole to the next hydrologic unit. This procedure is repeated as necessary to advance the borehole to the desired depth. Upon reaching the final target depth, the riser and screen is set through the inner casing. Subsequent to the placement of the filter packs and bentonite seal, the remaining annular space is grouted as described in 8.8.2 (see Fig. 3).

**NOTE 13**—When using a packer, pressure may build up during grout injection and force grout up the sides of the packer and into the casing.

**8.9 Well Protection**—Well protection refers specifically to installations made at the ground surface to deter unautho-







rized entry to the monitoring well and to prevent surface water from entering the annulus.

**8.9.1 Protective Casing**—The protective casing should extend from below the frost line (3 to 5 ft [1.0 to 1.5 m]) below the grade depending on local conditions to slightly above the well casing tip. The protective casing should be initially placed before final set of the grout backfill. The protective casing should be sealed and immobilized in concrete placed around the outside of the protective casing above the set grout backfill. The casing should be positioned and stabilized in a position concentric with the riser (see Figs. 1 and 2). Sufficient clearance, usually 6 in. (152 mm) should be maintained between the lid of the protective casing and the top of the riser to accommodate sampling equipment. A 1/4-in. (6.3-mm) diameter weep hole should be drilled in the casing 6 in. above the ground surface to permit water to drain out of the annular space. In cold climates, this hole will also prevent water freezing between the well protector and the well casing. Dry bentonite pellets, granules, or chips should then be placed in the annular space below ground level within the protective casing. Coarse sand or pea gravel or both is placed in the annular space above the dry bentonite pellets and above the weep hole to prevent entry of insects. All materials chosen should be documented on the well completion diagram. The monitoring well identification number should be clearly visible on the inside and outside of the lid of the protective casing.

**8.9.2 Completion of Surface Installation**—The well protection installation may be completed in one of three ways:

**8.9.2.1** In areas subject to frost heave, place a soil or bentonite/sand layer adjacent to the protective casing sloped to direct water drainage away from the well.

**8.9.2.2** In regions *not* subject to frost heave, a 4-in. (101-mm) thick concrete pad sloped to provide water drainage away from the well may be placed around the installation. Care must be taken not to lock the concrete pad onto the protective casing if subsidence of the surface may occur in the future.

**8.9.2.3** Where monitoring well protection must be flushed with the ground, an internal cap should be fitted on top of the riser within the manhole or vault. This cap should be leak-proof so that if the vault or manhole should fill with water, the water will not enter the well casing. Ideally, the manhole cover cap should also be leak-proof.

**8.9.3 Additional Protection**—In areas where there is a high probability of damaging the well (high traffic, heavy equipment, poor visibility), it may be necessary to enhance the normal protection of the monitoring well through the use of posts, markers, signs, etc. The level of protection should meet the damage threat posed by the location of the well.

## 9. Well Development

**9.1 General**—The development serves to remove the finer grained material from the well screen and filter pack that may otherwise interfere with water quality analyses, restore the ground-water properties disturbed during the drilling process and to improve the hydraulic characteristics of the filter pack and hydraulic communication between the well and the hydrologic unit adjacent to the well screen. Methods of well development vary with the physical characteristics of hydrologic units in which the monitoring well is screened

and with the drilling method used.

**9.2 Development Methods**—Methods of development most often used include mechanical surging and bailing or pumping, over-pumping, air-lift pumping, and jetting. An important factor in any method is that the development work be stated slowly and gently and be increased in vigor as the well is developed. Most methods of well development require the application of sufficient energy to disturb the filter pack, thereby freeing the fines and allowing them to be drawn into the well. The coarser fractions then settle around and stabilize the screen. The well development method chosen should be documented on the well completion diagram.

**NOTE 14**—Any time an air compressor is used, it should be equipped with an oil air filter or oil trap to minimize the introduction of oil into the screen area. The presence of oil would impact the organic constituent concentrations of the water samples.

**NOTE 15**—Development procedures for wells completed in fine sand and silt strata should involve methods that are relatively gentle so that the strain material will not be incorporated into the filter pack. Vigorous surging for development can produce mixing of the fine strata and filter pack and produce turbid samples from the installation. Also, development methods should be carefully selected based upon the potential contaminant(s) present, quality of waste water generated, and requirements for containerization or treatment of waste water.

**9.2.1 Mechanical Surging**—In this method, water is forced to flow into and out of the well screen by operating a plunger (or surge block) or bailer up and down in the riser. A pump or bailer should then be used to remove the dislodged sediments following surging.

**9.2.2 Over Pumping**—With this method, the monitoring well is pumped at a rate considerably higher than it would be during normal operation. The fine-grain materials would be dislodged from the filter pack and surrounding strata influenced by the higher pumping rate. This method is usually conducted in conjunction with mechanical surging.

**9.2.3 Air Lift Pumping**—In this method, an air lift pump is operated by cycling the air pressure on and off for short periods of time. This operation will provide a surging action that will dislodge fine-grained particles. Applying a steady, low pressure will remove the fines that have been drawn into the well by the surging action. Efforts should be made (that is, through the use of a foot valve) to avoid pumping air into the filter pack and adjacent hydrologic unit because the air may lodge there and inhibit future sampling efforts and may alter ambient water chemistry. Furthermore, application of high air pressures should be avoided to prevent damage to small diameter PVC risers, screens, and filter packs.

**9.2.4 Well Jetting**—Another method of development involves jetting the well screen area with water while simultaneously air-lift pumping the well. However, the water added during this development procedure will alter the natural, ambient water quality and may be difficult to remove. Therefore, the water added should be obtained from a source of known chemistry. Water from the monitoring well being developed may also be used if the suspended sediments are first removed.

**9.3 Duration of Well Development**—Well development should begin after the monitoring well is completely installed and prior to water sampling. Development should be continued until representative water, free of the drilling fluids, cuttings, or other materials introduced during well construc-







tion is obtained. Representative water is assumed to have been obtained when pH, temperature, and specific conductivity readings stabilize and the water is visually clear of suspended solids. The minimum duration of well development should vary in accordance with the method used to develop the well. For example, surging and pumping the well may provide a stable, sediment-free sample in a matter of minutes; whereas, bailing the well may require several hours of continuous effort to obtain a clear sample. The duration of well development and the pH, temperature, and specific conductivity readings should be recorded on the well completion diagram.

**9.4 Well Recovery Test**—A well recovery test should be performed immediately after and in conjunction with well development. The well recovery test not only provides an indication of well performance but also provides data for determining the transmissivity of the screened hydrologic unit. Estimates of the hydraulic conductivity of the unit can then be determined. Readings should be taken at intervals suggested in the table below until the well has recovered to 90 % of its static water level.

**NOTE 16**—If a monitoring well does not recover sufficiently for sampling within a 24-h period and the well has been properly developed, the installation should not generally be used as a monitoring well for detecting or assessing low level organic constituents. The installation may, however, be used for long-term water level monitoring if measurements of shorter frequency water level changes are not required.

## 10. Installation Survey

**10.1 General**—The vertical and horizontal position of each monitoring well in the monitoring system should be surveyed and subsequently mapped by a licensed surveyor. The well location map should include the location of all monitoring wells in the system and their respective identification numbers, elevations of the top of riser position to be

used as the reference point for water level measurements, and the elevations of the ground surface protective installations. The locations and elevations of all permanent benchmark(s) and pertinent boundary marker(s) located on-site or used in the survey should also be noted on the map.

**10.2 Water Level Measurement Reference**—The water level measurement reference point should be permanently marked, for instance, by cutting a V-notch into the top edge of the riser pipe. This reference point should be surveyed in reference to the nearest NGVD reference point.

**10.3 Location Coordinates**—The horizontal location of all monitoring wells (active or decommissioned) should be surveyed by reference to a standardized survey grid or by metes and bounds.

## 11. Monitoring Well Network Report

**11.1** To demonstrate that the goals as set forth in Section 1, the Scope, have been met, a monitoring well network report should be prepared. This report should:

**11.1.1** Locate the area investigated in terms pertinent to the project. This should include sketch maps or aerial photos on which the exploratory borings, piezometers, sample areas, and monitoring wells are located, as well as topographic items relevant to the determination of the various soil and rock types, such as contours, streambeds, etc. Where feasible, include a geologic map and geologic cross sections of the area being investigated.

**11.1.2** Include copies of all well boring test pits and exploratory borehole logs, initial and post-completion water levels, all laboratory test results, and all well completion diagrams.

**11.1.3** Include the well installation survey.

**11.1.4** Describe and relate the findings obtained in the initial reconnaissance and field investigation (Section 5) to the design and installation procedures selected (Sections 7 to 9) and the surveyed locations (Section 10).

**11.1.5** This report should include a recommended decommission procedure that is consistent with the well construction and local regulatory requirements.

## 12. Keywords

**12.1** aquifer; borehole drilling; geophysical exploration; ground water; monitoring well; site investigation

**TABLE 2 Suggested Recording Intervals for Well Recovery Tests**

Time Since Starting Test	Time Interval
0 to 15 min	1 min
15 to 50 min	5 min
50 to 100 min	10 min
100 to 300 min (5 h)	30 min
300 to 1440 min (24 h)	60 min

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that compound in the solute phase and the activity coefficient of that compound in the solute phase. This process is more clearly described by the following expression:

$$X^L_I \Gamma^L_I = X^W_I \Gamma^W_I \quad (1)$$

where:

$X^L_I$  = the mole fraction of compound ( $I$ ) in the liquid ( $L$ ) phase (free product),

$X^W_I$  = the mole fraction of compound ( $I$ ) in the solute ( $W$ ) phase (dissolved in water),

$\Gamma^L_I$  = the activity coefficient of compound ( $I$ ) in the liquid ( $L$ ) phase (free product), and

$\Gamma^W_I$  = the activity coefficient of compound ( $I$ ) in the solute ( $W$ ) phase (dissolved in water).

Dissolution equilibrium is therefore influenced by concentration of the subject compound in both the free product contaminant mixture and water. The most common practical application of expression Eq (1) in soil gas monitoring is in hydrocarbon detection. Simplification of Eq (1) is achieved by the following:

assume:

$$\Gamma^W_I = 1/S_I,$$

where:

$S$  = the solubility of compound ( $I$ ) in water

and:

$\Gamma^L_I = 1$ , acceptable for hydrocarbons (3),

then:

$$X^W_I = X^L_I S_I \quad (2)$$

4.3.2.1 Dissolution equilibrium is impacted by the presence of liquid phase cosolvents, such as gasoline additives, at low concentrations in liquid phase mixtures. This change in dissolution equilibrium can enhance the solubility of certain liquid phase components in water beyond what is indicated by partitioning coefficient data generated in the laboratory. This can have significant impact on downstream concentrations of the contaminant(s) in the soil atmosphere.

4.3.2.2 The effects of temperature upon dissolution equilibrium are generally insignificant for aliphatic hydrocarbons between 15 and 50°C (4), the temperature range from which most soil gas samples are recovered. However, temperature effects upon dissolution equilibrium can be significant for other common families of contaminant compounds within similar temperature ranges (5). These effects must be considered when planning or interpreting the results of a soil gas survey.

4.3.2.3 Dissolution equilibrium is altered by changes in water salinity. Modest decreases in the solubility of contaminants in water are to be expected with increases in salinity of the solution.

4.3.2.4 The rate of dissolution is strongly dependent upon the partitioning coefficient of the particular contaminant of interest and the amount of mixing of the liquid phase and water (3). For example, partitioning of a particular contaminant into ground water is accelerated by frequent water level fluctuations within a contaminated capillary fringe. The downstream implications for subsequent partitioning of the contaminant from the solute to the vapor phase for eventual soil gas recovery are obvious.

4.3.3 Volatilization is the process during which volatile contaminants move between the liquid phase (free product)

or solute phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. Contaminant mixtures can contain compounds with a considerable range of vapor pressures that can contribute contaminants to the soil atmosphere by volatilization. This atmosphere will exhibit a composition similar to that of the parent contaminant but lacking in those constituents with the lowest vapor pressures. The likelihood of the presence of a particular contaminant introduced into the soil atmosphere by volatilization can be estimated by considering the partial pressure of that contaminant in a vapor phase. This partial pressure is equal to the product of the mole fraction concentration of the subject component in the liquid contaminant solution, the activity coefficient of the subject component and the vapor pressure of the pure component. This concept is more clearly expressed as follows:

$$P = X_I \Gamma_I P^o \quad (3)$$

where:

$P$  = the partial pressure of the subject contaminant compound in the vapor phase,

$X_I$  = the mole fraction concentration of contaminant ( $I$ ) in the liquid contaminant solution,

$\Gamma_I$  = the activity coefficient of the subject contaminant in the liquid contaminant solution, and

$P^o$  = the vapor pressure of the pure component.

4.3.3.1 The quantity of contaminant volatilized into a vapor phase and the rate of that process is strongly dependent upon temperature. Rate of volatilization is also controlled by the rate of transport of contaminant vapors from the liquid phase-vapor phase interface (3). This rate is probably higher when macroporous flow paths are available for vapor phase transport, and is promoted by a number of driving forces. These are concentration gradient, density gradient between soil atmosphere and contaminant-saturated soil atmosphere, convection currents related to temperature gradient, barometric pressure pumping and introduction of water onto the liquid phase-vapor phase interface.

4.3.4 Air-water partitioning is the process by which volatile contaminants move between the solute phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. For dilute solutions, air-water partitioning is controlled by Henry's Law, which states that the vapor pressure of a volatile compound above a dilute aqueous solution of that compound is equal to the product of the Henry's Law constant and the mole fraction of that compound in the aqueous solution. Henry's Law may be represented as:

$$P_I = k X_{I(aq)} \quad (4)$$

where:

$P_I$  = vapor pressure of compound ( $I$ ) above a dilute aqueous solution of ( $I$ ),

$k$  = the Henry's Law constant for compound ( $I$ ) at a given temperature, and

$X_{I(aq)}$  = the mole fraction of the subject contaminant compound in the aqueous solution.

Care must be exercised in using Henry's Law to approximate contaminant vapor pressures because of unknowns related to the concentration of contaminants in solution and the contribution of other partitioning processes. Some available literature pertaining to soil gas surveying places emphasis on









## Standard Guide for Soil Gas Monitoring in the Vadose Zone<sup>1</sup>

This standard is issued under the fixed designation D 5314; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This guide covers information pertaining to a broad spectrum of practices and applications of soil atmosphere sampling, including sample recovery and handling, sample analysis, data interpretation, and data reporting. This guide can increase the awareness of soil gas monitoring practitioners concerning important aspects of the behavior of the soil-water-gas-contaminant system in which this monitoring is performed, as well as inform them of the variety of available techniques of each aspect of the practice. Appropriate applications of soil gas monitoring are identified, as are the purposes of the various applications. Emphasis is placed on soil gas contaminant determinations in certain application examples.

1.2 This guide suggests a variety of approaches useful to successfully monitor vadose zone contaminants with instructions that offer direction to those who generate and use soil gas data.

1.3 This guide does not recommend a standard practice to follow in all cases nor does it recommend definite courses of action. The success of any one soil gas monitoring methodology is strongly dependent upon the environment in which it is applied.

1.4 Concerns of practitioner liability or protection from or release from such liability, or both, are not addressed by this guide.

1.5 This guide is organized into the following sections and subsections that address specific segments of the practice of monitoring soil gas:

#### Section

- |     |   |
|-----|---|
| 4   | Summary of Practice   |
| 4.1 | Basic principles, including partitioning theory, migration and emplacement processes, and contaminant degradation |
| 4.7 | Summary Procedure   |
| 5   | Significance and Use  |
| 6   | Approach and Procedure  |
| 6.1 | Sampling Methodology  |
| 6.5 | Sample Handling and Transport   |
| 6.6 | Analysis of Soil Gas Samples  |
| 6.7 | Data Interpretation   |
| 7   | Reporting   |

1.6 *This guide does not purport to set standard levels of acceptable risk. Use of this guide for purposes of risk assessment is wholly the responsibility of the user.*

1.7 The values stated in either inch-pound or SI units are to be regarded separately as the standard. The values given in parentheses are for information only.

1.8 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
- D 1356 Terminology Relating to Atmospheric Sampling and Analysis<sup>3</sup>
- D 1357 Practice for Planning the Sampling of the Ambient Atmosphere<sup>3</sup>
- D 1452 Practice for Soil Investigation and Sampling by Auger Borings<sup>2</sup>
- D 1605 Practices for Sampling Atmospheres for Analysis of Gases and Vapors<sup>3</sup>
- D 1914 Practice for Conversion Units and Factors Relating to Atmospheric Analysis<sup>3</sup>
- D 2652 Terminology Relating to Activated Carbon<sup>4</sup>
- D 2820 Test Method for C<sub>1</sub> Through C<sub>5</sub> Hydrocarbons in the Atmosphere by Gas Chromatography<sup>3</sup>
- D 3249 Practice for General Ambient Air Analyzer Procedures<sup>3</sup>
- D 3416 Test Method for Total Hydrocarbons, Methane, and Carbon Monoxide (Gas Chromatographic Method) in the Atmosphere<sup>3</sup>
- D 3584 Practice for Indexing Papers and Reports on Soil and Rock for Engineering Purposes<sup>2</sup>
- D 3614 Guide for Laboratories Engaged in Sampling and Analysis of Atmospheres and Emissions<sup>3</sup>
- D 3670 Guide for Determination of Precision and Bias of Methods of Committee D-22<sup>3</sup>
- D 3686 Practice for Sampling Atmospheres to Collect Organic Compound Vapors (Activated Charcoal Tube Adsorption Method)<sup>3</sup>
- D 3687 Practice for Analysis of Organic Compound Vapors Collected by the Activated Charcoal Tube Adsorption Method<sup>3</sup>
- D 4220 Practices for Preserving and Transporting Soil Samples<sup>2</sup>
- D 4490 Practice for Measuring the Concentration of Toxic Gases or Vapors Using Detector Tubes<sup>3</sup>

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 04.08.

<sup>3</sup> Annual Book of ASTM Standards, Vol 11.03.

<sup>4</sup> Annual Book of ASTM Standards, Vol 15.01.







D4597 Practice for Sampling Workplace Atmospheres to Collect Organic Gases or Vapors with Activated Charcoal Diffusional Samplers<sup>3</sup>

D4696 Guide for Pore-Liquid Sampling from the Vadose Zone<sup>2</sup>

D4700 Guide for Soil Core Sampling from the Vadose Zone<sup>2</sup>

D5088 Practice for the Decontamination of Field Equipment Used at Non Radioactive Waste Sites<sup>5</sup>

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods<sup>6</sup>

E 260 Practice for Packed Column Gas Chromatography<sup>7</sup>

E 355 Practice for Gas Chromatography Terms and Relationships<sup>7</sup>

E 594 Practice for Testing Flame Ionization Detectors Used in Gas Chromatography<sup>7</sup>

E 697 Practice for Use of Electron-Capture Detectors in Gas Chromatography<sup>7</sup>

### 3. Terminology

#### 3.1 Descriptions of Terms Specific to This Standard:

3.1.1 *capillary fringe*—the basal region of the vadose zone comprising sediments that are saturated, or nearly saturated, near the water table, gradually decreasing in water content with increasing elevation above the water table. Also see Terminology D 653.

3.1.2 *contaminant*—substances not normally found in an environment at the observed concentration.

3.1.3 *emplacement*—the establishment of contaminant residence in the vadose zone in a particular phase.

3.1.4 *free product*—liquid phase contaminants released into the environment.

3.1.5 *free vapor phase*—a condition of contaminant residence in which volatilized contaminants occur in porosity that is effective to free and open gaseous flow and exchange, such porosity generally being macroporosity.

3.1.6 *liquid phase*—contaminant residing as a liquid in vadose zone pore space, often referred to as “free product.”

3.1.7 *macroporosity*—large intergranular porosity with large pore throats, including soil cracks, moldic porosity, animal burrows and other significant void space.

3.1.8 *microporosity*—intragranular porosity and microscopic intergranular porosity with submicroscopic pore throats.

3.1.9 *occluded vapor phase*—condition of contaminant residence in which volatilized contaminants occur in porosity that is ineffective to free and open gaseous flow and exchange, such porosity generally being microporosity; frequently termed dead-end pore space.

3.1.10 *partitioning*—the act of movement of contaminants from one soil residence phase to another.

3.1.11 *soil gas*—vadose zone atmosphere.

3.1.12 *solute phase*—a condition of contaminant residence in which contaminants are dissolved in ground water in either the saturated or the vadose zone.

3.1.13 *sorbed phase*—a condition of contaminant residence in which contaminants are adsorbed onto the surface

of soil particles or absorbed by soil organic matter.

3.1.14 *vadose zone*—the hydrogeological region extending from the soil surface to the top of the principal water table.

### 4. Summary of Guide

4.1 Soil gas monitoring in the vadose zone is a method used to directly measure characteristics of the soil atmosphere that are frequently utilized as an indirect indicator of processes occurring in and below a sampling horizon. Soil gas monitoring is used as a method to suggest the presence, composition, and origin of contaminants in and below the vadose zone. Among other applications, this method is also employed in the exploration for natural resources, including petroleum, natural gas and precious metals. Soil gas monitoring is a valuable screening method for detection of volatile organic contaminants, the most abundant analytical group of ground-water contaminant compounds (1).<sup>8</sup>

4.2 *Basic Theoretical Principles*—The processes indicated by the soil gas monitoring method are partitioning, migration, emplacement and degradation. Partitioning represents a group of processes that control contaminant movement from one physical phase to another, these phases being liquid, free vapor (that is, through-flowing air (2)), occluded vapor (that is, locally accessible air and trapped air (2)), solute and sorbed. Migration refers to contaminant movement over distance with any vertical, horizontal or temporal component. Emplacement refers to establishment of contaminant residence in any phase within any residence opportunity. Degradation is the process whereby contaminants are attenuated by oxidation or reduction in the vadose zone, either through biogenic or abiogenic processes. Soil gas monitoring measures the result of the interaction of these processes in a dynamic equilibrium. Measurement of these processes in static equilibrium is unrealistic.

4.3 The following subsections provide detailed information on partitioning, migration, emplacement and degradation. Subsection 4.4 provides a summary procedure for soil gas sampling. Users of this guide who do not wish to study details of partitioning, migration, emplacement and degradation at this time may skip to 4.4.

4.3.1 Partitioning is the initial step by which contaminants begin to move away from their source. Partitioning occurs in water saturated and unsaturated environments. This group of processes is complex and difficult to quantify when considered in the vadose zone due to the unique makeup of the vadose matrix, i.e. air-filled porosity (microporous and macroporous), pore water, free product, solid-phase soil organic matter, clay and discrete inorganic soil particles. Important individual processes of partitioning are dissolution, volatilization, air-water partitioning, soil-water partitioning and soil-air partitioning (3).

4.3.2 Dissolution is the process whereby volatile contaminants move between the liquid phase (free product) and the solute phase (dissolved in water). At equilibrium, the product of the mole fraction of a particular compound in the liquid phase and the activity coefficient of that compound in the liquid phase is equal to the product of the mole fraction of

<sup>3</sup> Annual Book of ASTM Standards, Vol 04.09.

<sup>6</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>7</sup> Annual Book of ASTM Standards, Vol 14.01.

<sup>8</sup> The boldface numbers given in parentheses refer to a list of references at the end of the text.







that compound in the solute phase and the activity coefficient of that compound in the solute phase. This process is more clearly described by the following expression:

$$X^L_I \Gamma^L_I = X^W_I \Gamma^W_I \quad (1)$$

where:

$X^L_I$  = the mole fraction of compound ( $I$ ) in the liquid ( $L$ ) phase (free product),

$X^W_I$  = the mole fraction of compound ( $I$ ) in the solute ( $W$ ) phase (dissolved in water),

$\Gamma^L_I$  = the activity coefficient of compound ( $I$ ) in the liquid ( $L$ ) phase (free product), and

$\Gamma^W_I$  = the activity coefficient of compound ( $I$ ) in the solute ( $W$ ) phase (dissolved in water).

Dissolution equilibrium is therefore influenced by concentration of the subject compound in both the free product contaminant mixture and water. The most common practical application of expression Eq (1) in soil gas monitoring is in hydrocarbon detection. Simplification of Eq (1) is achieved by the following:

assume:

$$\Gamma^W_I = 1/S_I$$

where:

$S$  = the solubility of compound ( $I$ ) in water

and:

$\Gamma^L_I = 1$ , acceptable for hydrocarbons (3),

then:

$$X^W_I = X^L_I S_I \quad (2)$$

4.3.2.1 Dissolution equilibrium is impacted by the presence of liquid phase cosolvents, such as gasoline additives, at low concentrations in liquid phase mixtures. This change in dissolution equilibrium can enhance the solubility of certain liquid phase components in water beyond what is indicated by partitioning coefficient data generated in the laboratory. This can have significant impact on downstream concentrations of the contaminant(s) in the soil atmosphere.

4.3.2.2 The effects of temperature upon dissolution equilibrium are generally insignificant for aliphatic hydrocarbons between 15 and 50°C (4), the temperature range from which most soil gas samples are recovered. However, temperature effects upon dissolution equilibrium can be significant for other common families of contaminant compounds within similar temperature ranges (5). These effects must be considered when planning or interpreting the results of a soil gas survey.

4.3.2.3 Dissolution equilibrium is altered by changes in water salinity. Modest decreases in the solubility of contaminants in water are to be expected with increases in salinity of the solution.

4.3.2.4 The rate of dissolution is strongly dependent upon the partitioning coefficient of the particular contaminant of interest and the amount of mixing of the liquid phase and water (3). For example, partitioning of a particular contaminant into ground water is accelerated by frequent water level fluctuations within a contaminated capillary fringe. The downstream implications for subsequent partitioning of the contaminant from the solute to the vapor phase for eventual soil gas recovery are obvious.

4.3.3 Volatilization is the process during which volatile contaminants move between the liquid phase (free product)

or solute phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. Contaminant mixtures can contain compounds with a considerable range of vapor pressures that can contribute contaminants to the soil atmosphere by volatilization. This atmosphere will exhibit a composition similar to that of the parent contaminant but lacking in those constituents with the lowest vapor pressures. The likelihood of the presence of a particular contaminant introduced into the soil atmosphere by volatilization can be estimated by considering the partial pressure of that contaminant in a vapor phase. This partial pressure is equal to the product of the mole fraction concentration of the subject component in the liquid contaminant solution, the activity coefficient of the subject component and the vapor pressure of the pure component. This concept is more clearly expressed as follows:

$$P = X_I \Gamma_I P^o \quad (3)$$

where:

$P$  = the partial pressure of the subject contaminant compound in the vapor phase,

$X_I$  = the mole fraction concentration of contaminant ( $I$ ) in the liquid contaminant solution,

$\Gamma_I$  = the activity coefficient of the subject contaminant in the liquid contaminant solution, and

$P^o$  = the vapor pressure of the pure component.

4.3.3.1 The quantity of contaminant volatilized into a vapor phase and the rate of that process is strongly dependent upon temperature. Rate of volatilization is also controlled by the rate of transport of contaminant vapors from the liquid phase-vapor phase interface (3). This rate is probably higher when macroporous flow paths are available for vapor phase transport, and is promoted by a number of driving forces. These are concentration gradient, density gradient between soil atmosphere and contaminant-saturated soil atmosphere, convection currents related to temperature gradient, barometric pressure pumping and introduction of water onto the liquid phase-vapor phase interface.

4.3.4 Air-water partitioning is the process by which volatile contaminants move between the solute phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. For dilute solutions, air-water partitioning is controlled by Henry's Law, which states that the vapor pressure of a volatile compound above a dilute aqueous solution of that compound is equal to the product of the Henry's Law constant and the mole fraction of that compound in the aqueous solution. Henry's Law may be represented as:

$$P_I = k X_{I(aq)} \quad (4)$$

where:

$P_I$  = vapor pressure of compound ( $I$ ) above a dilute aqueous solution of ( $I$ ),

$k$  = the Henry's Law constant for compound ( $I$ ) at a given temperature, and

$X_{I(aq)}$  = the mole fraction of the subject contaminant compound in the aqueous solution.

Care must be exercised in using Henry's Law to approximate contaminant vapor pressures because of unknowns related to the concentration of contaminants in solution and the contribution of other partitioning processes. Some available literature pertaining to soil gas surveying places emphasis on







Henry's Law constant at 25°C and atmospheric pressure as a primary controlling factor in determining the suitability of a particular volatile contaminant to the soil gas monitoring method. Such emphasis may be inappropriate when, for example, free product is the source of contaminant vapors or when contaminants have not reached ground water. Care must also be exercised in noting the units in which Henry's Law constants are expressed, as these vary from source to source. Volatile but very highly water soluble compounds behaving according to Henry's Law may not be detectable in soil gas because of their persistence for residence in the solute phase (6).

4.3.5 Soil-water partitioning is the process by which volatile contaminants move between the sorbed phase and the solute phase. This process is generally underestimated in its importance to the success or failure of contaminant recovery by soil gas sampling, especially when utilizing the majority of active soil gas sampling techniques generally available to field personnel.<sup>9</sup> There is uncertainty with respect to factors controlling soil-water partitioning, creating doubt as to the reliability of soil sorption data in most applications. Problems with soil sorption data include variability in measurement protocols, the variable nature of organic matter in soils, the effect of dissolved organic matter, unusual pH effects and the effect of salinity, among others (3).

4.3.5.1 The contribution of soil-water partitioning to contaminant phase residence equilibria is strongly controlled by sorbed contaminant concentration in soil, soil makeup, vadose zone pore water content, and soil porosity configuration. Important variables in soil makeup are the quantity, type and distribution of clay in soil and the quantity, type and distribution of soil organic matter. These variables impact the surface area available to sorptive processes, that is, the storage capacity of the soil for contaminants in the sorbed phase, and the pH of the sorption environment. Variations in vadose zone pore water content directly affect the storage capacity of the soil for contaminants in the solute phase. Soil porosity configuration, principally microporosity versus macroporosity, is critical to the rate of soil-water partitioning due to the contrast in surface area between micropores and macropores and the related storage capacity of this porosity for both pore water and sorbed contaminants.

4.3.6 Soil-air partitioning is the process by which volatile contaminants move between the sorbed phase and a vapor phase, either the free vapor phase or the occluded vapor phase or both. Like soil-water partitioning, this process is underestimated in its importance to the recoverability of contaminants by many soil gas sampling techniques. In vadose zone horizons with very low pore water contents, soil-air partitioning can yield vapor phase contaminant composition that differs from free product composition. In vadose zone horizons with higher pore water content, the responsibility for this compositional inconsistency is shared, largely with soil-water partitioning. In wet soil conditions, threshold soil water content values exist for trapped soil atmosphere content to become significant (7), suggesting that

responsibility for this compositional inconsistency can be largely attributed to occluded phase residence. Additional important variables are soil clay content, type and distribution, and soil organic matter content, type and distribution. Studies have demonstrated significant impact of soil organic matter and clay content on volatile organic compound emissions from soils (8). Due to the strong control on vapor phase contaminant content by the soil-air partitioning process, it is unreasonable to expect soil contaminants with high affinity for sorption to be efficiently recovered by most soil gas sampling techniques.

4.4 Migration of contaminants in the vadose zone, that is, unsaturated flow, is highly complex and is controlled by soil characteristics, contaminant composition and contaminant phase (9). Migration through unsaturated matrix can occur through a variety of diffusion, dispersion and mass transport mechanisms which behave in a manner unique to saturated flow.

4.4.1 A major division in migratory behavior of contaminants is defined by their solubility or immiscibility in water. Contaminants are often introduced into the soil as liquid mixtures, the components of which immediately begin to partition into other phases upon soil entry. Contaminants that establish soil residence behind a migratory front change in composition with distance from their point of entry. As contaminant migration continues, pathways for individual components can become divergent, such that the composition of the liquid mixture continues to change as migration proceeds. Eventually, migration of liquid mixtures may reach ground water. This can be retarded if the contaminants partition into other phases before reaching ground water and if contaminant vapor is less dense than the uncontaminated soil atmosphere. Transport of contaminants by downward percolation of meteoric waters and upward movement of ground water accelerate the contact of contaminants with ground water. When these contaminants do reach ground water, a radically different set of migration mechanisms begins to govern contaminant transport via saturated flow. Further divergence of contaminant pathways is dependent upon the tendency of each component of the contaminant mixture to float on ground water, become dissolved in ground water or sink to an impermeable layer within the aquifer. Detailed descriptions of these phenomena are available in the literature (10).

4.4.2 The impact of migration processes on soil gas measurement is significant. Although it is impractical to estimate actual migration mechanisms by modelling prior to most soil gas monitoring efforts, a rudimentary knowledge of site characteristics can guide investigators to realistic interpretations of soil gas data expressing unusual or highly variable compositions. More thorough knowledge of relevant site characteristics, such as the presence or absence of barriers to vertical or horizontal migration, that is, foundations, buried pavement, or perched ground water, as well as preferential pathways for contaminant migration, that is, backfill rubble, utility vaults, storm sewers or soil cracks, can assist investigators to assess the migration impact on soil gas survey design.

4.5 The vadose zone is a highly complex soil-air-water-hydrocarbon system with abundant opportunity to store contaminants in all phases. Contaminants partition ac-

<sup>9</sup> See 6.2 for a discussion of active soil gas sampling techniques.







cording to their physical properties and the residence opportunity presented to them along their migratory path. This process has been described as an in-situ chromatographic-like separation of contaminants (11). Emplacement, or the establishment of contaminant residence, is a highly dynamic process. Contaminants move from one phase to another as changes occur in both chemical and physical equilibria. Important changes impacting phase residence change include temporal variations in moisture content, soil temperature and level of microbial activity.

4.5.1 One interesting example of disruption in equilibrium conditions is the act of sampling soil gas. Many soil gas sampling systems rely on large volume recovery of soil gas to provide a sample that is believed to be representative of the soil atmosphere in situ. Movement of this soil gas by convective flow through unsaturated soils can cause upward changes in vapor phase contaminant concentration at the expense of other phases.

4.5.2 In natural systems, temporal increases in soil moisture cause gradual increases in solute phase emplacement at the expense of other phases. It is unrealistic to attempt to characterize a static soil gas equilibrium in the vadose zone because this equilibrium is never achieved. For this reason, soil gas data sets based on specific contaminant concentrations and generated at different times are usually not comparable for the absolute values generated by each temporal sampling event. Qualitative comparison of data generated by the same soil gas method and performed at different times is permissible. Generation of a single data set by reconnaissance soil gas sampling and subsequent infilling of data to form a single data set is strongly discouraged.

4.5.3 Attempts to compensate for temporal variations in phase equilibria have been attempted by collecting samples that approximate replicates at known locations and adjusting succeeding data up or down to compensate for observed changes. This procedure is also strongly discouraged, because the number of variables affecting observed changes are too great. Moreover, the ability or willingness of most investigators to determine the most significant effects upon phase equilibria is insufficient to be of use.

4.5.4 Data sets generated by different soil gas sampling techniques may not be comparable as a direct result of differences in efficiency of recovery of contaminants from specific phases. Not only can these data sets differ in measured contaminant concentration, but they can vary substantially in composition as well.

4.6 Degradation of contaminants occurs in the vadose zone through oxidation or reduction reactions that can be biogenic or abiogenic in nature. This process can occur both aerobically and anaerobically to mitigate contaminant levels. Degradation is most often recognized in shallow, permeable soils where favorable conditions exist for oxidation of labile compounds, however other vadose environments can be conducive to degradation. Specific environmental conditions are required for degradation processes to occur. For abiogenic degradation, redox potential and soil pH can be rate controlling factors. For biodegradation, necessary environmental conditions include the presence of microorganisms capable of adaptation to the contaminant as substrate, conditions favorable to population increases of these microorganisms and migration pathways for contaminants to

come in contact with these microorganisms. Most soils contain naturally occurring populations of various microorganisms that can degrade petroleum products (12). Contaminant biodegradation is known to occur in groundwater (13) and in soils (14) prior to contaminant partitioning into a vapor phase. Contaminant biodegradation rates for some compounds are highly variable and are controlled by a number of kinetic factors influencing the distribution of microorganisms responsible for degradation. These include aerobic versus anaerobic environments, contaminant type and temperature (15, 16).

4.6.1 Degradation rate can approach, equal or periodically exceed the rate of contaminant emplacement into the vadose zone, such that contaminants are not detectable by soil gas monitoring. This mechanism can result in soil gas data which are not representative of an underlying contaminated condition (17).

4.6.2 Labile contaminants can be degraded to compounds that may or may not be detectable in soil gas. Aerobic degradation can produce carbon dioxide which can be monitored as an indirect indicator of the presence of contaminants (18), or organic acids and phenols (13) that are not routinely detectable in active whole air soil gas samples. In alternative to whole air methods, use of an appropriate adsorption medium may facilitate recovery of such compounds for analysis by desorption and gas chromatography-mass spectroscopy. Anaerobic degradation can produce compounds including methane, ethylene, propylene, acetylene, and vinyl chloride which also can be monitored as an indirect indicator of the presence of contaminants. Caution must be used in attributing elevated levels of these compounds to biodegradation, because competitive processes can confuse the interpretation of absolute concentration values and potential sources.

4.6.3 Biodegradation of contaminants in the vadose zone can proceed naturally by adaptation of indigenous microbial populations to metabolize contaminants as primary substrate, or by introduction of foreign populations which have been preconditioned to metabolize contaminants of interest. Case histories demonstrate the absence of certain compounds in soil gas contaminant suites for which biodegradation has been named as the responsible process (17, 19, 20). Such cases address the attenuation or complete absence of simple aromatic hydrocarbons, some of which are halogenated, in soil gas. This phenomenon may be controlled by the availability of oxygen as has been demonstrated in the laboratory (13). Other compound classes can exhibit similar effects.

4.6.4 Other processes may share responsibility for the actual or apparent absence or attenuation of some contaminants in soil gas sample sets. In some cases where attenuation of contaminant concentration is attributed to degradation, combinations of high soil clay, organic matter and pore water content can reduce the recovery efficiency of certain soil gas sampling techniques for certain contaminants such that contaminant concentrations fall below detection limits. Care must be exercised in attributing a lack of contaminants in soil gas samples to degradation.

4.7 *Summary Procedure for Soil Gas Sampling*—Vadose zone monitoring methods have a set of procedures, both general and specific, that must be consistently followed in







order to provide maximum data quality and usefulness. Soil gas monitoring is no exception, with six primary procedures common to all soil gas monitoring techniques. The procedures are a planning and preparation step including definition of data quality objectives, the act of sampling soil gas in the field, handling and transporting the sample, sample analysis, interpretation of the results of analysis, and preparation of a report of findings.

4.7.1 The planning and preparation step begins with the formulation of project objectives, including purpose of the survey, appropriate application of the data to be collected and data quality objectives.

4.7.2 Data can vary in quality due to sampling methodology, sample preparation, analytical procedures, laboratory quality control, and available documentation. Quality assurance programs include all of the activities necessary to provide measurement data at a requisite precision and bias (see Practice 1357). Quality assurance objectives for soil gas monitoring are similar to those for atmospheric air monitoring. The overall quality assurance objective for measurement data is to ensure that data of known and acceptable quality are provided. In order to meet these objectives, data quality objectives should be defined for data measurements in support of the soil gas data interpretation. These are comparability, completeness, representativeness, bias and precision. The comparability of the data collected refers to the ability to interpret the results in light of previous data collection efforts. Completeness refers to the number of samples collected and analyzed compared to the planned number of samples. Representativeness is a measure of the degree to which analytical results reflect true field conditions. Field contamination and sampling intensity are two factors affecting representativeness. Bias is a generic concept of exactness related to the closeness of agreement between the average of one or more test results and an accepted reference value (see Practice E 177). The precision of a measurement process is a generic concept related to the closeness of agreement between test results obtained under prescribed like conditions from the measurement process being evaluated. Overall precision and bias targets for chemical contaminant measurements can be set at 10 % allowable deviation with 90 % confidence limits. In all of these quality assurance activities one must take into consideration that factors including geophysical conditions and definition of sampling volume in the vadose zone often have higher variability than analytical equipment calibration procedures.

4.7.3 Table 1 provides suggested quantitative limits for data quality objectives.

4.7.4 The planning and preparation step continues with the evaluation of available information already gathered for the project area. These efforts culminate in the selection of an appropriate soil gas monitoring method and a survey design which best fits the project objectives within budgetary constraints. Prior to actual field work, investigators must obtain the necessary permits and landowner permission for property access. When a survey area is pending sale, investigators should obtain written permission to conduct the survey from both the buyer and the seller. Moreover, when a soil gas survey is being performed as a service, no work should proceed on the survey without a fully executed consulting agreement between the investigator and the client

TABLE 1 Suggested Quantitative Limits for Data Quality Objectives

QA/QC Objective	Measure	Formula	Limit
Accuracy	Laboratory standard	Standard recovery	90 to 110 %
Precision	Field replicate	Relative standard deviation	< 20 %
	Laboratory replicate	Relative standard deviation	< 20 %
Representativeness	Air blank	Bias	< 10 %
	Cross contam. blank	Bias	< 10 %
Completeness	Completion (%)	Relative compl.	> 90 %
Comparability	Prof. judgment	NA	NA

for whom the survey is being conducted.

4.7.5 Actual field work consists of recovery of soil gas samples. The method selected should be based upon site specific factors and dictated by the project objectives. A detailed discussion of soil gas sampling methods is provided in 6.1.

4.7.6 As samples are being recovered, they must be handled and transported in such a way as to assure preservation prior to analysis. A detailed discussion of sampling and transport is located in 6.5.

4.7.7 The presence of contaminants is determined through analysis of the soil gas samples. This step is controlled to a large degree by the QA/QC objectives of the survey. A discussion of sample analysis is provided as 6.6.

4.7.8 Data interpretation is largely an iterative process of review of the raw soil gas data out of context, a review of the soil gas data in context of other site characteristics and the formulation of conclusions based upon all known information. A discussion of soil gas data interpretation is located in 6.7.

4.7.9 Finally, a report of findings is generated in a format that is selected to be appropriate to the requirements of the end users. Section 7 provides options that can be addressed in reporting as well as recommendations of topics that should be included in all soil gas summations.

## 5. Significance and Use

5.1 *Application of Soil Gas Monitoring*—Soil gas monitoring is an extremely versatile method in that it can be adapted to conform to the requirements of dissimilar industries for a wide variety of applications. A number of soil gas techniques have been utilized in the agricultural (21), petroleum (22, 23) and minerals (24) industries. Certain applications have been exercised for well over 50 years. Soil gas monitoring has been utilized in research efforts, including the monitoring of underground coal gasification retorts (25). Application to the environmental industry is comparably recent but very effective as a rapid and relatively inexpensive method of detecting volatile contaminants in the vadose zone. Field screening, of which soil gas monitoring is a basic component, has been demonstrated to be effective for selection of suitable and representative samples for other more costly and definitive monitoring methods (26). Soil gas monitoring is useful to assess the extent of ground water contamination for certain contaminants and field environments (27). Soil gas monitoring is also a viable method of monitoring subsurface contaminant discharges from underground storage tanks (28). New applications of the soil gas







monitoring are periodically developed and published in the referenced literature. The method may be useful in the study of unsaturated flow. In most instances, the method can make use of very light-weight, portable and inexpensive tools made from commonly available materials. Soil gas monitoring has become a widely accepted method for locating subsequent environmental monitoring and remediation activities such as ground water monitoring wells, contaminant product recovery wells or excavations to recover contaminated soil. Soil gas monitoring has made a significant contribution to ground water monitoring and remedial planning on sites that fall under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (29). This method is highly useful at the initiation of Phase II environmental assessment action in determining the presence of volatile organic contamination of real property in a pending sale.

5.1.1 In any application, soil gas monitoring can be performed over a wide range of both spatial and temporal designs. Spatial designs include soil gas sampling in profiles or grid patterns at a single depth or multiple depths. Multiple depth sampling is particularly useful for contaminant determinations in cases with complex soil type distribution and multiple sources. Depth profiling can also be useful in the determination of the most appropriate depth(s) at which to monitor soil gas, as well as the demonstration of migration and degradation processes in the vadose zone. Temporal designs include the long-term monitoring of the vadose zone for the appearance of volatile organic contaminants from known potential sources such as underground storage tanks and solid waste landfills. Temporal designs are especially useful in monitoring the effectiveness of contaminant remediation efforts.

5.1.2 Soil gas monitoring in the vadose zone is an ideal reconnaissance tool and screening technique in most applications. However, site specific and contaminant specific limitations can cause this technique to be unsuccessful in meeting project objectives. Caveats exist in all soil gas monitoring procedures that can frustrate efforts to successfully apply the method to any application.

5.2 *Limitations*—The most significant limitation on soil gas monitoring is the inability to utilize the method as a stand alone technique. Soil gas monitoring does not provide repeatable quantitative information over time due primarily to the dynamic nature of phase equilibria in the vadose zone and secondarily to unavoidable inconsistencies in sampling practice. As a result of geologic variability in the vadose zone and the multitude of unique sampling devices currently being used in the field, quality assurance and quality control protocol, discussed in 6.4, cannot provide the rigor required as in a test method. For these reasons, soil gas data in itself cannot be used to provide definitive answers about the location or absence of buried contaminants. Moreover, the success of any soil gas monitoring method is strongly dependent upon effects related to geologic variation and moisture content in the sampling horizon as well as the physical properties of the target contaminants.

5.2.1 False negative results can occur as a direct result of the incompatibility of a specific procedure with the properties of the sampling horizon or the target contaminants, or both. Soil gas data cannot be used to establish bulk volume

or the commerciality of buried petroleum, natural gas, or ore bodies.

5.2.2 With the necessary analytical procedures, soil gas can be examined for compositional anomalies, a very useful technique for multiple source problems. In some instances, contaminant occurrences are limited to single species (compounds, mercury, etc.), however more often than not the contaminant source is a mixture of organic chemicals that have a unique chemical compositional character consisting of both normally evaluated priority pollutants and non-priority pollutant chemicals that may be overlooked. By identifying and using compositional information, many problematic site situations such as degradation can be minimized by targeting the more refractory compounds associated with the contaminant occurrence. This interpretive method is impossible to model for an industry wide application due to variation in methods and technique.

5.2.3 A basic limitation of the technique is that due to the ease of procurement and use of soil gas sampling devices, there is a tendency for inexperienced personnel to oversimplify any and all aspects of the method. Investigators must consider the experience level and technical ability of personnel who acquire soil gas samples and attempt to interpret the results. Certain procedural facets are not trivial, as discussed in Section 6. The results of certain techniques tend to be affected by minor variations in procedure despite apparent adherence to a "Standard Operating Procedure."

5.2.4 Atmospheric air contamination is not a trivial problem corrected by simple device-oriented field practice. Many sampling systems recover very large volumes of "soil gas" that may actually represent a mixture of soil gas and atmospheric air. This mixing occurs through the introduction of ambient air adjacent to the sampling device and through macroporous pathways in the soil which are far from the sampling device. Some environmental investigators avoid the impact of this problem by reasoning that contaminant quantities in the soil are so great that they are detected despite atmospheric mixing. For qualitative approaches with non-rigorous quality assurance/quality control (QA/QC) objectives this mixing problem can be insignificant. For detection of compounds that exhibit only marginal partitioning preference for the free vapor phase, the mixing problem can be a fatal flaw in procedure. Moreover, contaminant concentration and composition investigations can be rendered useless by variations in the magnitude of mixing at various sample locations and depths in a survey area.

5.3 *Comments on Limitations of Soil Gas Monitoring*—Many investigators believe that soil gas monitoring is not an effective vadose zone monitoring method for certain volatile organic applications, in certain geographic regions or during certain seasons of the year, or both. The applicability of soil gas monitoring is controlled by physical and chemical properties and processes in the subsurface and not by factors that are obvious at or above the surface. For example, one common misconception is that soil gas monitoring is not effective during the winter season. The impacts upon soil gas measurement of elevated soil pore water content, reduced vadose zone temperature and the presence of frost, typical of numerous regions in winter, are obvious for many facets of most soil gas monitoring methods. Modification of standard operating procedure, such as an increase in sampling depth,







or selection of another soil gas monitoring method altogether can minimize the negative impacts of seasonal field conditions. It is important to understand that the responsibility for success or failure in soil gas monitoring can reside as much in the planning phase of a survey, including the method chosen, as in factors controlling the chemical and physical processes at work in the subsurface. Even with apparently ideal field conditions and with a carefully planned survey, soil gas monitoring can succeed or fail due to unknown factors controlling contaminant migration and emplacement. Soil gas monitoring is no different than any other measurement method, in that investigators must maximize effort in planning and implementation of procedure to maximize the likelihood of success.

## 6. Approach

**6.1 Sampling Methodology**—Soil gas sampling methodology has evolved over time and through practice in several industries. The equipment with which to perform this monitoring technique is highly varied, although it may be categorized into basic types (see 6.2.2). The literature provides numerous discussions about the design of some of this equipment (10, 30, 31, 32, 33). The selection of a soil gas sampling method involves consideration of three primary issues. These are the type of sampling system, the methodology of application of that sampling system and the rigor of the field QA/QC protocol. Each of these issues is discussed in this guide, however, no single method or procedure is recommended to the reader due to the variation in site specific factors. As many as one hundred unique soil gas sampling systems exist that arise from variations or combinations, or both, of the many facets described in this guide. Some systems are highly versatile for numerous applications. Others are functional for more limited or specific applications. Informed investigators must assume the responsibility of selecting the technique most appropriate to the subject application, whether that technique is commercially available from contractors or equipment suppliers, or reliant upon the ingenuity of the investigator in the field utilizing commonly available materials. Success in choosing an appropriate sampling device or an entire sampling system is dependent upon the investigator's level of understanding of vadose zone processes, contaminant properties and appropriate applicability of the soil gas method.

**6.1.1** The application of any of these methods must be controlled by strict adherence to a standard operating procedure. Occasional deviations as dictated by unusual field conditions should be recorded in the project field notebook. Inadvertent minor deviations in field procedure can result in misinterpretation of the data acquired.

**6.2 Sampling Systems**—Six basic sampling systems exist. These are based upon the collection of soil gas by a whole-air or sorbent method in an active or passive approach, or upon the principle of collection of a soil or water sample for subsequent sampling of a contained headspace atmosphere. Contained atmosphere methods do not yield samples representative of in situ vadose zone atmospheres.

**6.2.1 Whole-air methods** sample the soil atmosphere as a mixture of gases, including contaminant and non-contaminant vapors. Sorbent methods sample contaminants adsorbed onto a collection medium exposed to a whole-air

sample stream. Active methods are those that obtain a soil gas sample by positioning a sampling device in the subsurface and the withdrawal of soil atmosphere through the device from the sampling horizon. Passive methods are those that obtain a soil gas sample by placing a collection device in the soil or on the soil surface, and allowing the atmosphere within the device to come into compositional equilibrium with the soil atmosphere. Four of the six basic sampling systems arise from these approaches, namely the whole air-active approach, the sorbed contaminants-active approach, the whole air-passive approach, and the sorbed contaminants-passive approach. Two additional systems exist that are based respectively upon the collection of a soil or water sample for subsequent sampling of a small volume headspace atmosphere.

**6.2.2 Whole Air-Active Approach**—This method of soil gas sample collection involves the forced movement of bulk soil atmosphere from the sampling horizon to a collection or contaminant device through a probe or other similar apparatus (10, 34). Contained samples of soil atmosphere are then transported to a laboratory for analysis, or the sampling device is directly coupled to an analytical system. Whole air-active sampling is best suited to soil gas monitoring efforts where contaminant concentrations are expected to be high and the vadose zone is highly permeable to vapor. Probes exist that must utilize pre-existing holes or that can penetrate the vadose zone by driven means. These devices can be very simple and light-weight for low cost mobilization (35), or they can be affixed to vehicle mounted drills or hammers useful for larger, more complex surveys at a higher cost of mobilization. The whole air-active technique can be combined with other monitoring methods such as soil monitoring for engineering purposes (36) in some survey environments. The success of this practice can be highly site-specific.

**6.2.2.1 Ground probes** can be of small to large internal volume. The development of sampling devices with smaller internal volumes equating to smaller purge volumes is a significant improvement, providing samples which are more representative of soil atmosphere, and a greater ease of equipment decontamination between usages. Sample size can vary from a few millilitres to many tens of litres depending upon the sample rate through the probe, the vapor storage capacity of the soil and the ability of the soil to deliver vapor to a probe under vacuum.

**6.2.2.2** The success of the active approach is strongly dependent upon soil clay, organic matter and moisture content. Driven probes tend to destroy natural soil permeability around the body of the probe due to soil compaction concurrent with insertion. This can be a severe limitation in moist, heavy clay soils. In very dry, cemented soils, driven probes can create radial fractures that can enhance soil permeability to vapor concurrent with insertion. These fractures can communicate atmospheric air with soil atmosphere, a limiting factor for obtaining representative, large-volume soil gas samples. The effect can be so severe as to lower recovered contaminant concentrations in the soil gas sample below the limits of analytical detection. This is especially true for highly sorptive or water soluble compounds, or both. Some investigators have attributed the poor







recoveries of these compounds exclusively to other processes, that is, degradation (21, 37).

6.2.2.3 Methods requiring a pre-existing hole for probe insertion (38) made with a commercially available "slam bar" can provide supportable contaminant data where contaminant concentrations and soil permeability to vapor are high, however the act of making a hole with a "slam bar" and subsequent removal of the "slam bar" can encourage soil contaminant venting and lower sample representativeness. Insertion of the sampling probe into this hole further degrades representativeness by additional venting of contaminants as the probe displaces the atmosphere in the hole upon insertion. Purging of the probe prior to sampling under conditions of low soil permeability and low contaminant concentration may lower contaminant levels below the limits of analytical detection. Methods requiring a pre-existing hole for probe insertion are not recommended for soil gas sampling from soils with high clay and moisture contents.

6.2.2.4 Excellent discussions of numerous whole air-active sampling systems may be found in the literature (10, 21, 37, 39). Investigators must consider the caveats and limitations of the whole air-active approach when selecting a certain method for a specific application.

6.2.3 *Sorbed Contaminants-Active Approach*—The sorbed contaminants-active method of soil gas sample collection also involves the forced movement of bulk soil atmosphere from the sampling horizon through a probe or other similar apparatus, but to a collection device designed to extract and trap sample stream contaminants by adsorption (40, 41). This system is well suited to sites where the soil may be highly permeable to vapor and where the contaminant concentration may be lower than required for successful whole-air surveys. Sorbent devices are designed to concentrate the components of interest and remove some of the soil gas components known to interfere with sample analysis.

6.2.3.1 Contaminant trapping is accomplished by use of an adsorbent collection medium such as charcoal or a carbonized molecular sieve adsorbent (43, 44), as well as porous polymers, silica gel and activated alumina (10). This approach is especially amenable to the detection of nonpolar volatile organic compounds. Organic compounds that are reactive, oxygenated or are gaseous at room temperature are either not adsorbed by or are not efficiently desorbed (42) from charcoal. Sorbent collection devices are commercially available or can be specially prepared with an appropriate sorbent material that concentrates desired compounds for future analysis. Colorimetric detector tubes are available which will provide an indication of the presence of target compounds at the time of sampling. These devices are limited in application by the high concentration requirements for many compounds and the compound-specific nature of these tubes.

6.2.3.2 The effectiveness of the sorbed contaminants-active approach can be limited by high vadose zone clay and water content, reducing the ability of the soil to transmit vapor through the sorbent trap. Commercially available sorbent traps come with information suggesting maximum, minimum and optimum sampling rate through the trap. Soil characteristics can limit flow rate to a point below the minimum recommended rate, affecting the performance of the trap and the reproducibility of adjacent samples. Interac-

tion of the sorption media with target compounds during desorption in the laboratory can form artifacts, restricting the interpretive value of the data. Some sorption media are prone to irreversible adsorption (see Definitions D 2652). Some may be affected by high soil gas relative humidity. Humidity greater than 60 % (very common for soil gas) can reduce the adsorptive capacity of activated charcoal to 50 % for some chemicals. Presence of condensed water in the sample tube will indicate a suspect sample (see Practice D 3686). Anticipation of these problems is recommended for all sorbent techniques, and a thorough quality control plan should be designed and implemented as is discussed in 6.4 of this guide.

6.2.3.3 Special sample preparation is required for samples adsorbed onto a trapping medium. This preparation step consists of the thermal or solvent desorption of the contaminants from the trapping medium. Proper practice will promote needed accuracy and precision in the determination of contaminant concentrations above specified values (see Practice D 3687).

6.2.4 *Whole Air-Passive Approach*—This method of soil gas sample collection involves the entry of bulk soil atmosphere or soil atmosphere components from a near-surface sampling horizon to a collection or containment device through a flux chamber or other similar apparatus (30). Enclosure devices sample vaporous emissions from a known soil surface area capped by a chamber. The volume of the chamber is continuously swept by injection of a gas of known composition, and the resultant carrier gas-contaminant mixture is collected for analysis. The rate of emission or "flux" of contaminants can be calculated if flow rate of injected gas and contaminant concentration in the sample are determined.

6.2.4.1 The whole air-passive approach is useful to some very specific applications. This method may be used, for example, to monitor contaminant emissions from soil or water to assess the health hazard risk of such emissions to the general public. Determination of the extent of contamination by volatile organic compounds has been performed with whole air-passive devices, however the application of other types of systems is far more common.

6.2.4.2 A key to successful operation of a whole air-passive system is that the system is able to recover volatile compounds as they are emitted from the vadose zone. The effects of changes in barometric pressure, soil temperature and soil moisture content are not quantifiable from site to site due to site specific variables controlling vapor phase contaminant migration and the rate of contaminant partitioning into the vapor phase. The presence of contaminants or naturally occurring organic matter floating on surface water may impact the rate of entry of certain vapor phase contaminants into the chamber.

6.2.4.3 The whole air-passive method is limited in application primarily due to the great degree of dilution of contaminants in the sample stream by injected gas. This can decrease method sensitivity by lowering contaminant concentrations to levels below the detection limits of the analysis method chosen. Further decrease in method sensitivity results from the fact that soil gas contaminant concentrations are generally lower at the surface than even at nominal depths. Soil characteristics such as high water saturation, soil







cements, clay content and organic matter content will negatively impact results of these systems by restricting the rate of contaminant flux to the chamber.

6.2.4.4 Additional limitations exist. Certain devices limit flux rates into the chamber due to aspects of design. Soil macroporosity such as desiccation cracks extending beyond the collecting device will vent soil vapors to the atmosphere that will not be collected by flux chambers unless monitoring locations are biased to include these features.

6.2.5 *Sorbed Contaminants-Passive Approach*—This method of soil gas sample collection involves the passive movement of contaminants in soil to a sorbent collection device over time. Passive samplers that have been applied to sampling soil gases of environmental concern include occupational health volatile organic compound monitors (44) and a sampler originally developed for detecting the presence of hydrocarbons in petroleum exploration (33, 46). Both devices use charcoal as a sorbent; the former as a flat film and the latter coated on a wire. Passive samplers are housed in containers up to several inches in diameter, depending upon the design. They are placed open end down in holes that are usually less than 5 ft (1.5 m) deep, that are then backfilled (32). These monitors are generally left in place from two to ten days, although certain passive collectors can be left in place for a period of 30 days or more for certain applications. For at least one device, exposure efficiency can be determined.

6.2.5.1 The sorbed contaminants-passive approach can be employed in a wide range of geological conditions. Frozen ground and high water saturation may not limit the ability of the monitors to collect contaminants (46), although the composition of the contaminant suite may be impacted by related alterations in partitioning equilibria.

6.2.5.2 The sorbed contaminants-passive approach depends upon the ability of contaminants to move through the vadose zone to the passive collection device. Numerous adsorption media can be used to collect contaminants (see 6.2.4). The principle of passive-sorbent monitors relies on adsorbent reduction of the equilibrium concentration of contaminants around the monitor over time, therefore creating a concentration sink, that is, a continuous state of disequilibrium, in the vicinity of the monitor. This can encourage continued migration of contaminants toward the monitor when conditions for contaminant partitioning into the vapor phase are favorable. Migration of contaminants in the vadose zone toward a passive-sorbent device is strongly controlled by vadose zone character and the chemical and physical properties of the subject contaminants. Contaminants may move from a few feet to thousands of feet, or not at all.

6.2.5.3 Many investigators attribute the principle mechanism of contaminant migration to a passive-sorbent device to diffusion, that is, the movement of organic vapor or gas molecules from a region of high concentration to a region of low concentration as described by Fick's law (see Practice D 4597). Fick's law of diffusion states that for a constant concentration gradient, the mass of material transferred to the sampling layer can be expressed as:

$$M = \{DA(C - C_o)t\}/L \quad (5)$$

where:

$M$  = mass of the material, ng,

$D$  = diffusion coefficient,  $\text{cm}^2/\text{min}$ ,

$A$  = cross sectional area of diffusion cavity(s),  $\text{cm}^2$ ,

$L$  = length of diffusion path, cm,

$C$  = concentration at face of sampler,  $\text{ng}/\text{cm}^3$ ,

$C_o$  = concentration at adsorbing layer surface,  $\text{ng}/\text{cm}^3$ , and

$t$  = exposure time, min.

6.2.5.4 The cross sectional area of a diffusion cavity, the length of the diffusion path and the quantity  $(C - C_o)$  are impossible to accurately measure for soil gas contaminants interacting with a passive-sorbent sampler. There is some debate as to whether passive samplers measure flux or total contaminant concentration (32) in the vicinity of the trap. Due to the fact that the mass of the material transferred to the sampler by diffusion, a key measurement, cannot be determined, the debate will no doubt continue. It is reasonable to assume that a combination of processes is responsible for contaminant migration to sorbent traps, including diffusion, dispersion and mass transfer. All migration processes are impacted by partitioning equilibria.

6.2.5.5 Ambient air represents an atmospheric contaminant concentration sink that encourages a strong vertical vector of contaminant migration. This prevailing upward movement of contaminants from sources at depth results in contaminant concentration gradients throughout the vadose zone. The sorbed contaminants-passive method makes use of this contaminant flux (see 6.2.4) to collect long-term, nondisruptive samples of volatile contaminants. The method can collect contaminants which are compositionally representative of the contaminant mixture favoring the vapor phase. The quantity of volatile organic compounds trapped by these devices is proportional to the concentration gradients of contaminants present near the collection device and the affinity of the contaminant(s) for the collection medium.

6.2.5.6 As with active sampling protocols, specific issues exist affecting the function and calibration of passive monitors. Soil gas, even in the drier climates, will be at a relatively high humidity condition. This humidity can affect the collection efficiency of the adsorbent media. In soils of low permeability, contaminants commonly move very slowly. This can create a condition of near-zero contaminant concentration in the soils immediately adjacent to the monitor if the sorptive potential of the monitor is higher than that of the soil. When soil contaminant concentrations are rapidly depleted, that is, as the result of invasion of the sampling horizon by meteoric water, the passive monitor can source contaminants back to the soil.

6.2.5.7 The sorbed contaminant-passive approach to soil gas monitoring is not immune to the migration, emplacement and degradation factors affecting all soil gas monitoring techniques. It is not possible to measure the efficiency of passive-sorbent monitoring devices because the bulk volume of soil gas affected by the sorbent trap cannot be measured. Care must be taken not to contaminate the sorbent samples during installation or by backfilling with contaminated soil. Such care is comparable to potential problems for any measurement method in which a contaminated layer is penetrated.

6.2.6 *Soil Sampling for Subsequent Headspace Atmosphere or Extraction Sampling*—This method examines contaminants that are present in a headspace atmosphere







above a contained soil sample. Note well that this headspace atmosphere is not true soil gas (see 3.1.11), but is an artificial atmosphere formed above a potential contaminant source, that is, the soil sample. Contained atmosphere methods do not yield samples representative of in situ vadose zone atmospheres. Headspace atmospheres differ from in situ vadose zone atmospheres in that large percentages of vapor phase and moderate percentages of solute and sorbed phase contaminants can be lost in the act of soil sampling. This method is not generally recommended for a broad spectrum of cases due to numerous limitations and caveats. In comparison to other methods described in this guide, soil sampling for subsequent headspace atmosphere or extraction sampling can be a relatively poor method for determining many of the more volatile contaminants. Headspace atmospheres contain residual sorbed and solute phase contaminants that have partitioned to the vapor phase in the contained environment; most headspace approaches are reasonably efficient in recovery of some fraction of sorbed and solute phase contaminants. Contaminants in these phases in situ are recovered from a headspace after they have partitioned into the vapor phase. Recovery efficiency of contaminants in the vapor phase in situ ranges from moderate to poor.

6.2.6.1 Important criteria exist to consider when selecting a device that will provide suitable samples (see Guide D 4700). The equipment required is simple and readily available. Some commonly used augers are not suitable for soil sampling in support of subsequent headspace atmosphere sampling due to soil disturbance. Depths of auger investigations are limited by ground water conditions, soil characteristics and the equipment used (see Practice D 1452). Suitable procedures for some methods are described in the literature (47, 48). Current soil preservation practice may not apply (see Practice D 4220).

6.2.6.2 Limitations and special procedures exist for the application of soil sampling for subsequent headspace gas analysis. Filling head space with solvent can support a subsequent solvent extraction procedure. Some investigators minimize the effects of devolatilization by rapidly recovering small soil core plugs with polypropylene syringes which have been modified to accommodate recovery of soil plugs. Investigators also attempt to maximize partitioning of contaminants into the vapor phase by adding buffering solutions or sodium sulphate and phosphoric acid to the vial prior to sealing, in order to shift the activity coefficients of the subject contaminants to favor the vapor phase. Aqueous suspensions of solvent slurries of soil can be ineffective for the determination of high molecular weight labile compounds. Their persistence in soil is the result of physical entrapment in soil microporosity (49). Recovery efficiency of contaminants in soil headspace can be greatly enhanced by pulverization of the soil (50) in a ball mill or other similar apparatus. The method is biased toward recovery of contaminants in the sorbed, solute and occluded phases in situ due to the loss of pore space gas in preference to contaminants adsorbed onto the soil particles or trapped in soil micropores. Contaminant degradation, especially biodegradation, in the container is encouraged by the creation of an aerobic, moist environment during sample handling and transport prior to analysis. However, a simple method to minimize the effects of

biodegradation can be achieved by storing samples, when necessary, at approximately 4°C in the dark.

6.2.6.3 Acid extraction of volatile organic compounds is widely used in geochemical exploration for petroleum and natural gas. Soil samples are placed in a closed vessel, heated and evacuated to remove vapor phase contaminants. The addition of acid to the evacuated chamber causes release of hydrocarbons believed to be bound to the soils by carbonates (22). Hydrocarbons are determined by analysis of resulting vessel atmospheres. Refinements to this method have been developed (48), however the method is designed not to determine compounds in the vapor, sorbed, or solute phases. Method sensitivity is therefore greatly reduced.

6.2.7 *Soil Pore Liquid Headspace Gas Approach*—In the vadose zone, soil gas monitoring can be accomplished in combination with soil pore liquid sampling through the use of a suction lysimeter, a pan lysimeter or a free drainage glass block sampler. The suction lysimeter installed in the vadose zone is most commonly employed for this purpose. Temporally designed surveys are ideally suited to this method.

6.2.7.1 After a lysimeter has been installed for some period of time, initial aliquots of vapor sampled from a soil pore liquid sampler will be in compositional equilibrium with solute phase contaminants when pore liquid tensions are within the operating range of the lysimeter and if pore sizes are not so great as to cause loss of hydraulic contact between the soil and the porous segment of the lysimeter. Subsequent aliquots of soil gas may compositionally resemble soil vapor in situ if soil atmosphere enters the porous segment of the sampling device. When the lysimeter cannot recover a pore liquid sample, the soil gas recovered will be compositionally similar to soil vapor in situ.

6.2.7.2 The most common effort to recover soil gas from a suction lysimeter occurs when polytetrafluoroethylene (PTFE) porous segments are employed in sampling environments with high soil moisture tensions (low moisture contents). At tensions above 60 to 80 centibars, soil pore liquid samples cannot be collected (see Guide D 4696). However, soil gas can be recovered through the porous segment and collected at the surface. This alternative sampling effort can monitor soil vapor contaminants utilizing an otherwise unsuccessful procedure until soil moisture contents increase or until an alternative soil pore liquid sampler can be installed.

6.2.7.3 This technique is limited by the relative expense and complexity of installation of the sampling devices as a primary soil gas sampling method. The completeness criterion for quality assurance is difficult to satisfy due to the inability to anticipate the performance of the soil pore liquid sampler with respect to vapor recovery. Moreover, compositional bias toward solute phase contaminants and contaminants volatilized from free product is likely in soil gas samples recovered concurrently with soil pore liquid samples.

6.3 *Methodology in Application of a Sampling Technique*—The likelihood of success of the soil gas sampling technique selected is controlled in part by the methodology in application of that sampling technique. This methodology should be guided by the objectives of the subject project and the perceived spatial and temporal array of the potential sampling targets.







6.3.1 *Grids*—Many problems suitable for soil gas monitoring are best solved by obtaining data distributed over a geographic area. Sampling in grid patterns of variable design and spacing can be a very effective way to provide data coverage over a large area for a very low cost of acquisition. Common applications of soil gas grid sampling are environmental contaminant assessments, exploration for natural resources and the siting of locations for other monitoring or exploratory techniques. Compositional analyses in conjunction with properly designed grid systems are often fundamental to successful evaluation of soil gas monitoring.

6.3.1.1 Grid spacing provides for the location of soil gas samples in grid cells. The selection of grid cell size is strongly dependent upon the relationship between project confidence level requirements and cost budget. Small survey targets and complex vadose zone geology require decreased spacing between soil gas sample locations for grid methodology to be successful. Some applications, for example, defining the boundaries of contaminated soil or ground-water contaminant plumes, may require the grid cell area to be as small as 100 to 400 ft<sup>2</sup> (9 to 37 m<sup>2</sup>). Most applications to natural resource exploration monitor naturally occurring volatile compounds in soil atmospheres, requiring closely spaced grids to increase the signal to noise ratio. However, a closely spaced exploratory grid equates to a broadly spaced grid for environmental application in most situations. Common petroleum exploration grid spacing utilizes a grid cell area of approximately 250 000 ft<sup>2</sup> (23 000 m<sup>2</sup>), however grid cells can range from 10 000 to 1 000 000 ft<sup>2</sup> (9 to 90 000 m<sup>2</sup>) depending upon perceived reservoir target area. Widely spaced grid sample arrays are useful in reconnaissance applications such as the establishment of contaminant baselines or evaluation of the exploration potential of a geologic basin. Grid cells for such purposes can be as large as a square mile or more.

6.3.1.2 The tendency exists for investigators with constrained budgets to utilize overly large grid cell spacings. This action normally results in inadequate, over-interpreted data supporting meaningless conclusions. Care must be taken to avoid this caveat.

6.3.1.3 Grid arrays can be designed as regularly spaced and predetermined locations for soil gas sampling or they can be irregularly spaced and continually field modified. Predetermined and widely spaced grid patterns are most useful for reconnaissance work, while closely spaced, irregularly situated or field modified soil gas grid sample sites, or both, are commonly used when targeting contaminant plume boundaries, contamination from underground storage tanks or other detail work.

6.3.1.4 Multiple depth sampling, discussed in 6.3.3, when coupled with a soil gas grid sampling methodology, can provide useful data in complex geologic settings and sites with multiple contaminant sources. Computer mapping of closely spaced three-dimensional soil gas grids can provide the investigator with horizontal or vertical cross sections through the subject site, making difficult observations possible.

6.3.2 *Profiling*—Profiling is a soil gas sampling methodology useful to test a linear array for the existence of contaminants. Profiling is most often performed by sampling at closely spaced intervals in a linear array and is displayed as

contaminant concentration or composition versus distance sampled on an  $X - Y$  plot. Concentration data are often displayed logarithmically on the ordinate ( $Y$ ) axis, while single components or ratios of compositional data are often displayed linearly on the ordinate axis.

6.3.2.1 For environmental applications such as leak detection along the length of a pipeline or monitoring of contaminant encroachment across a property boundary, soil gas samples are recovered along a profile at intervals from 25 to 100 ft (8 to 30 m) (23). Profiling for natural resource exploration can be performed at sample intervals from 50 to 500 ft (15 to 50 m), depending upon the application.

6.3.2.2 Profiling is useful as a corroborative tool for other monitoring or exploration methods. For example, a soil gas sample profile acquired coincident with a seismic profile can suggest primary contaminant migration pathways or the boundaries of confining layers in shallow, complex geologic settings. This technique has been demonstrated as highly effective in reducing exploratory risk prior to drilling for petroleum and natural gas, by suggesting the presence of hydrocarbon seepage coincident with structures with reservoir potential defined by the seismic method (51).

6.3.2.3 Soil gas profiling is also a convenient methodology effective in comparative evaluation of multiple soil gas sampling techniques. Due to variations common to the dynamic equilibrium conditions over small spatial and temporal intervals in the vadose zone (see 4.1), comparisons of multiple soil gas techniques using only one or a few soil gas samples recovered from nearly identical locations will not result in a valid comparison. However, a visual overlay of soil gas profiles resulting from the implementation of the various sampling techniques can provide a rapid and definitive comparison as to the efficiency of recovery of subject contaminants by a particular sampling system in a specific sampling environment. Similarly, comparison of profiles obtained by using the same soil gas sampling system can provide a direct measurement of system accuracy for quality control purposes.

6.3.2.4 Some investigators compare geographically coincident profiles obtained with the same sampling system at times differing by days or even years in order to generate a data correction factor in order to enhance data comparability. This practice is strongly discouraged. Factors not anticipated in this practice such as the effects of the dynamic equilibrium in the vadose zone, unavoidable changes in procedure due to personnel substitutions, contaminant movement or cultural influence on the sampling environment can have impact on results that are far more significant than the apparent correction.

6.3.3 *Multiple Depth Sampling*—Methodologies encompassing multiple depth sampling normally have one of two goals, that is, to monitor changes in soil gas contaminant fractions versus depth, and to closely follow a single sampling horizon for an entire soil gas grid or profile.

6.3.3.1 When the goal of a survey is to monitor contaminants over varying depths, some sampling systems can recover soil gas samples as probes are advanced deeper into the vadose zone. This practice is helpful in determining the optimum sampling depth for a particular site or to demonstrate the presence or absence of soil atmosphere contamination in a certain horizon. Soil gas contaminant concentrations often increase with depth as the sampling horizon







approaches contaminated ground water or other source of soil gas contaminants (52). Caution must be exercised when soil gas sampling tools are advanced to increasing depths due to the fact that cross contamination of some or all of the sampling system is unavoidable. This situation limits quality control for this type of multiple depth sampling. Attempts to eliminate cross contamination in multiple depth sampling by replacement or decontamination of sampling equipment with each new sample aliquot also result in limited quality control. Tool withdrawal and tool reinsertion result in venting of the sampling environment via an open hole. The open hole behaves as a macroporous pore space, allowing enhanced partitioning into the vapor phase and convective migration to the atmosphere. The end result is a reduction in representativeness for each subsequently recovered soil gas sample.

6.3.3.2 Multiple depth sampling can also be used to focus a sampling program into a single geologic unit or suite of units without regard to depth. This practice is helpful at sites with complex lithologic changes in the vadose zone. Samples can be recovered from lithologies with greater permeability to vapor or greater storage capacity for vapor when bias in sampling depth is necessary to accomplish project goals. This practice involves greater effort and expense than most methodologies due to the necessity to establish the presence, thickness and depth of the target horizons prior to soil gas sampling. The most common application of this methodology is the sampling of soil gas at the top of the capillary fringe.

6.3.4 *Time Variant Methodologies*—Monitoring soil gas in the vadose zone over time can suggest process rates of contaminant partitioning, emplacement, migration and degradation. Practical application of this methodology includes the monitoring of the effectiveness of remedial air-injection systems, the appearance of contaminants sourced from underground storage tanks, the encroachment of contamination onto a subject property from an abutting property and the mitigation of soil and ground-water contamination by microorganisms.

6.3.4.1 Some investigators and regulators with responsibilities at more than one location delegate seemingly simple time variant soil gas monitoring tasks to local personnel. Numerous problems with time variant monitoring can arise in the field as the result of poor system maintenance and record keeping by inexperienced or unmotivated personnel (property owners or parties responsible for contamination).

6.3.4.2 Certain maintenance problems are easily corrected, that is, cleaning bacteria and other foreign matter from detectors or replacing damaged components. Other maintenance problems can be fatal flaws in the methodology. These are principally related to ice formation in the sampling system and destruction of system integrity due to soil frost heaving.

6.3.5 *Combination of Soil Gas Monitoring With Other Vadose Zone Monitoring Techniques*—Soil gas monitoring is not a stand-alone technique. Corroborative support of this reconnaissance and screening tool by other vadose zone monitoring techniques is strongly encouraged. The possible combinations of the various vadose zone techniques with soil gas surveys are numerous. Soil gas can commonly be used as a reconnaissance tool to locate other monitoring devices

such as lysimeters, neutron probes or ground water monitoring/sampling wells. Limits upon such combinations are controlled by budgetary constraints and the investigator's imagination.

6.4 *Field QA/QC*—Quality assurance and quality control procedures (QA/QC) are essential to establishing support for any interpretation of measurement data. Soil gas monitoring data requires a thorough QA/QC protocol confirming that data have been generated to satisfy the data quality objectives for the survey. This requirement is well known, however few investigators subject their soil gas data sets to the rigors of such protocol. Conclusions based upon data of unknown quality may be without merit. Justification for interpretations based upon data of unknown quality is not possible.

6.4.1 QA/QC requirements are dependent upon the data quality objectives defined in the planning phase of the survey. For example, simple contaminant audits require a less demanding QA/QC protocol than contaminant source identification. The goals of the QA/QC effort must be understood by field personnel to assure effective implementation of field QA/QC. A document control officer who is a member of the field team can provide this assurance.

6.4.2 Persons collecting descriptive data should not be varied during a soil gas survey. Soil descriptions, for example, can be somewhat subjective when estimations are made as to soil moisture or clay content. Changes in field personnel can translate into apparent changes in soil lithology that are merely functions of this subjectivity. The document control officer can review field records to discover any obvious errors related to descriptive data.

6.4.3 The results of a soil gas survey are highly sensitive to procedure. Field personnel should closely follow a standard operating procedure. This procedure should include the method(s) selected for the survey including the sampling system, means of sample collection, handling and transport of samples and field based equipment decontamination. A standard practice for equipment decontamination is essential to maximize the integrity of samples that may undergo chemical analyses (see Practice D 5088). Any deviations in the standard operating procedure should be recorded by the document control officer in a field notebook, with notes outlining the justification for the deviation. Data comparability can be severely compromised by deviations from the standard operating procedure.

6.4.4 Field based equipment decontamination can have impact on data quality. This results from the potential for cross contamination of samples due to poorly controlled field cleaning procedure or difficulties presented by the inconvenience of field decontamination. Field based equipment decontamination should not be considered a method of choice, but if unavoidable, must be performed with the data quality objectives for the survey as driving forces for procedure.

6.4.5 Bias of soil gas data describes a situation of consistently lower-than-actual or higher-than-actual soil gas contaminant concentration measurements (32). The bias of a measurement process is a generic concept related to consistent or systematic difference between a set of test results from the process and an accepted reference value of the property being measured (see Practice E 177). Bias can be imparted to







the data through sample site selection, that is, exposure of a sampling device to an environment of enhanced contaminant concentration due to a preferential contaminant migration pathway, or exposure of a sampling device to an environment devoid of contaminants due to barriers to contaminant migration. Bias may also result from malfunction of the sampling system, contaminant degradation or numerous other factors. False positive or false negative values can result, lowering the value of the soil gas data set.

6.4.6 Table 2 summarizes some common problems in soil gas monitoring that can result in biased results.

6.4.7 A sampling program must be conducted during the survey to support evaluation of both the sampling system in the field and the analytical system employed. These samples are known as QA/QC samples. The type and magnitude of QA/QC sampling depends upon the purpose of the soil gas survey and the requirements for data quality attendant to it. It is the responsibility of the investigator to determine the appropriate rigor of field QA/QC protocol. The variation in QA/QC protocol from survey to survey is controlled by the purpose and magnitude of the survey, and can vary to a great degree.

6.4.8 The types of field QA/QC samples are field blanks, travel blanks, sample container blanks, sample probe blanks and sample replicates. Other types of QA/QC samples are analytical in nature and are discussed in 6.6.

6.4.9 Field blanks are samples of ambient air or nitrogen recovered from the sampling system which are recovered to determine contamination of samples by ambient atmospheric air, or, to act as system blanks to test for contamination of the sampling system. Field blanks are used to provide an indication of the probability of leakage in the sampling system or the breakthrough of atmospheric air to the sampling device through macroporous migration pathways in the vadose zone such as soil cracks or moldic porosity. If nitrogen is employed instead of atmospheric air, field blanks can have higher contaminant levels than soil gas. This is especially true for petroleum hydrocarbons in urban environments. At least one field blank should be recovered for each ten soil gas samples, or at least one field blank per sample batch or container type (53).

6.4.10 Travel blanks are the contents of a sample container handled in the same manner as those containers holding samples, except that there has been no sample inserted into the travel blank. The purpose for travel blanks

is to audit sample integrity for loss due to sample handling and transport. Travel blanks are useful when analysis is performed at an off-site laboratory. The results obtained by analysis of travel blanks can be used to indicate a potential need to modify sample handling and transport procedure. At least one travel blank should be included in each batch of samples.

6.4.11 Sample container blanks are obtained by sampling the contents of a clean sample container to ensure that residual contaminants are not present in the container prior to sample collection. If contamination is detected in the cleaned containers, the decontamination procedure must be modified to remedy the problem. Sample container blanks should be collected and analyzed prior to each use of a sample container.

6.4.12 Sample probe blanks, consisting of carrier gas or atmospheric air contrasted to atmospheric air blanks, are drawn through the sampling device and recovered in the same manner as soil gas. The purpose for sample probe blanks is to check for the presence of sample train contaminants that would impact data quality. If contaminants are detected in sample probe blanks, the decontamination procedure must be modified to remedy this condition. Sample probe blanks should be collected and analyzed prior to each use of a probe and/or other components of the sampling system.

6.4.13 Field replicates are recovered as separate soil gas samples collected from the same sample site into multiple containers. Field replicates can be used to estimate the combined precision of sampling and analysis. The recovery of field replicates is not a common practice. When field replicates are demanded by a client or as dictated by a particular situation, field replicates should be recovered as often as is economically and practically possible, however in no instance should the number of replicates fall below ten percent of the total number of soil gas samples (53).

6.4.14 Sample spiking, or the addition of a known quantity of a known compound or mixture to the soil gas sample, is sometimes performed in the field to provide internal checks of analytical quality. Sample spiking in the field is not recommended due to measurement uncertainties in the field. Moreover, caution must be exercised with this procedure because of the potential for contaminant interaction with the known compound(s).

6.4.15 A paperwork audit is recommended at the end of each working day or at the conclusion of recovery of each batch of samples recovered. The paperwork audit should be conducted by the document control officer and include evidence of an equipment inventory, sample inventory including QA/QC samples, review of field notes and chain-of-custody documentation.

6.4.16 Chain-of-custody documentation is recommended at all times, and is mandatory for soil gas surveys when samples are transmitted to an off-site laboratory. It is recommended for soil gas surveys when sample custody is transferred to someone other than the field team leader for any reason. Chain-of-custody documentation assures that samples have not been altered or mishandled prior to analysis. This procedure is mandatory for sample handling and transport in situations where there is likely to be a cost

**TABLE 2 Summary of Possible Causes of False Positive and False Negative Values<sup>a</sup>**

Result	Causes
False negatives, that is, falsely low values	Barriers to gaseous diffusion, such as perched water, clay lenses, impervious man-made debris, saturation of soil pores with water (as from rain), low subsurface temperatures.
	Biological or chemical degradation.
	Leakage or blockage in the sample train, improper purge procedure, loss of sample from sample container, problem with analytical system.
False positives, that is, falsely high values	Contamination in sampling train, sample container, or analytical system.
	Contribution of volatile organic contaminants from vegetation.
	Significant contamination in overlying soil.

<sup>a</sup> See Ref (32).



